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U.S. Army Environmental Center

Composting of Nitrocellulose Fines - Regulatory and Logistical Feasibility - BAAP Installation

Report No. SFIM-AEC-ET-CR-95087
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13. ABSTRACT (Maximum 200 words) The production of nitrocellulose for munitions purposes results in the production of nitrocellulose fines (NC fines). BAAP currently has stored approximately 500 tons of NC fines (dry basis). Composting has been evaluated as a means of managing these fines and yielding a nonreactive beneficial soil amendment.

This report describes the regulatory logistical and feasibility of the following end-use options for the finished NC fines compost: (1) land application (with harvesting) by the installation; (2) providing local farmers with compost as a soil amendment; (3) application for mining reclamation; and (4) disposal of the compost in a landfill. Mining reclamation was not logistically feasible. All of the end-use options were found to be feasible with regard to regulatory constraints. Because finished NC compost is not specified in federal or Wisconsin state regulations for solid waste, the nonhazardous nature of the compost needs to be assured through demonstration of nonreactivity and/or chemical content determination. Based on predicted compost application rates, the anticipated 450 tons/year of compost would require approximately 320 acres/year of land. Based on preliminary site selection criteria, these land requirements appear to be achievable. Costs per ton of compost range from $20/ton for supply to local farmers to $90/ton for application by the installation.

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EXECUTIVE SUMMARY

The production of nitrocellulose for munitions purposes results in the production of nitrocellulose fines (NC fines). The Army is evaluating methods to recover these NC fines or recycle them into usable products. An alternative for the management of nonrecoverable NC fines derived from the production of nitrocellulose is biological treatment via composting. Previous pilot testing at Badger Army Ammunition Plant (BAAP) indicated that NC can be degraded via composting. Composting has the potential to eliminate the reactivity characteristic of NC fines. It also has the advantage of yielding a beneficial finished compost suitable for use as a soil amendment.

BAAP has NC fines stored on-site from past NC production operations. NC is not currently produced at BAAP.

Previous reactivity testing has shown that NC fines in a compost matrix with a moisture content of 30%, at loading rates between approximately 10 and 35%, may be handled safely.(12) Further, the composting process was determined to be economically feasible, at a cost of approximately $310/yd^3 of NC fines.(12)

The composting process is anticipated to yield a nonreactive soil amendment suitable for beneficial reuse. This report describes the logistical and regulatory feasibility of the following end-use options:

- Land application (with crop harvesting) by the installation.
- Providing local farmers with compost as a soil amendment.
- Landfilling the finished NC fines compost.

All three of these end-use options were found to be feasible with regards to regulatory constraints, including buffer zone and application rate restrictions and various permitting requirements. However, as finished NC compost is not specifically mentioned in federal or Wisconsin state regulations for solid waste, nonreactivity needs to be demonstrated and chemical content determined to assure the nonhazardous nature of the compost. A fourth option, mining reclamation, was also considered; however, because no surface mines are located within a 100-mile radius of BAAP, this option was considered not to be feasible and therefore was dropped from further analysis.

To apply the anticipated 450 tons/year of finished compost, approximately 320 acres/year of land will be needed, based on predicted application rates. Table ES-1 presents approximate annual costs for each end-use option. Based on preliminary site selection criteria such as slope, current land use, and proximity to the BAAP installation, it appears that adequate land exists in the vicinity of the installation and at the installation itself to satisfy the acreage requirements. Properties would have to be evaluated on an individual basis prior to final selection. Additionally, chemical characterization of the finished compost would need to be performed to finalize application rates based on crop nutrient needs.

Table ES-1

Annual Cost Summary of End-Use Alternatives for NC Fines Compost

Alternative	Estimated Annual Cost ($/year)	Estimated Cost per Ton of Finished Compost ($/ton)[a]	Estimated Cost per Ton of Original NC Fines ($/ton)[b]
Land application by the installation	$59,400	$90	$260
Providing local farmers with compost as a soil amendment	$8,300	$20	$40
Landfilling the finished NC fines compost	$40,500	$65	$180

[a] Based on 640 tons/year of compost, wet basis.
[b] Based on 225 tons/year of NC fines, dry basis.

SECTION 1
INTRODUCTION

1.1 BACKGROUND

The manufacture and handling of explosives and propellants at Army Ammunition Plants (AAPs) and Army Depots (ADs) have resulted in the production of various types of wastes, which require appropriate treatment and management to minimize and control their environmental impact. The U.S. Army Environmental Center (USAEC), formerly the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), has responsibility for evaluating and developing cost-effective treatment technologies to meet the goals of the Army's environmental program.

One propellant by-product for which the USAEC is evaluating treatment options is the solids, or fines, derived from the production of nitrocellulose (NC). NC fines from past production operations are stockpiled in tanks at Badger Army Ammunition Plant (BAAP), in Baraboo, Wisconsin. The actual material to be treated consists of NC fines as produced during NC manufacture. One technology that the USAEC has considered for NC fines is biological treatment via composting.

NC is a highly substituted cellulose fiber, which is synthesized from cellulosic materials such as wood pulp or cotton, and used by the Army as a propellant (alone or in combination with other constituents) in munitions and rocket motors. NC is produced from the cellulosic material by nitration using nitric and sulfuric acids, followed by various additional processing steps. [1,2] The degree of nitration can be varied by adjusting acid strength and processing conditions. As a result, NC may contain from 11.11% nitrogen (cellulose dinitrate) to a theoretical level of 14.14% nitrogen (cellulose trinitrate), although practically achievable nitrogen levels are on the order of 13.8%.[1,2,3,4] The higher nitrogen forms are primarily used in munitions, while lower nitrogen forms are used in various products in the coatings, film, ink, and adhesives industries. [1,2]

Manufacture of NC results in the production of NC fines, which are difficult to recover during production due to their small size. These NC fines have historically been discharged with process water into lagoons. Fines that settled in the lagoons were periodically removed for recycling into product or for storage.

While NC fines are not considered toxic by the U.S. Environmental Protection Agency (EPA),[5] they may be reactive under certain conditions. The Army is investigating options to maximize both the recovery of NC fines and the recycle of NC fines into useful product.[6] The USAEC is evaluating composting as a method for treating NC fines that have not or cannot be effectively recovered or recycled into product. Previous testing by the USAEC has shown that composting can treat NC fines in soils.[7,8]

Composting is a treatment process in which organic materials are biodegraded by microorganisms, generally at elevated temperatures. The biodegradation process results in the production of (among other things) metabolic heat, which is trapped within the compost matrix and results in so-called "self-heating" of the compost pile. As historically used for such high-organic wastes as wastewater treatment plant biosolids, municipal solid wastes (MSW), and agricultural or yard wastes, this elevated temperature process may meet the following goals:

- Stabilization of organic matter.
- Reduction in the treated material volume requiring further management.
- Reduction in moisture content (drying).
- Destruction of pathogenic microorganisms.

By contrast, the principal objective of composting of hazardous or chemical wastes is the efficient and rapid removal or destruction of specific regulated waste constituents or properties. Previous research conducted by USAEC has shown that a variety of nitroaromatic explosives in soils can be treated by composting.[9,10,11] Additional work has shown the treatment of NC in soils is technically achievable.[7,8] Finally, a recent economic analysis has shown that composting of NC fines is an economically feasible treatment alternative. [12]

Due to the energetic nature of explosives and propellants, which can result in detonation under shock or thermal stimuli, safety criteria and procedures to avoid shock and thermal stimuli are of critical importance in all materials handling aspects of treating NC. Establishing safety criteria includes considering the levels of contamination that can safely be handled in the treatment process. NC is known to be a reactive material, particularly when dry. An assessment of the levels of NC fines that can be safely handled in a compost matrix is given in *Composting of Nitrocellulose Fines - Hazards Analysis.* [12]

Because the NC fines hazards analysis report showed that composting can be economically feasible at NC fines levels considered to be safe in a compost matrix, end-use options for the finished compost also must be considered. As stated previously, EPA does not consider NC fines to be toxic. [5] Therefore, if the composting process eliminates the material's reactivity, finished NC fines compost should be able to be used as a beneficial soil amendment. As such, this report will include summaries of various end-use options and their potential costs. Also, a summary of applicable regulations for the options is included.

1.2 SITE BACKGROUND

BAAP is located on a 7,354-acre site in Sauk County, Wisconsin (see Figure 1-1). Constructed in 1942, the plant operated intermittently over a 33-year period, producing single- and double-base propellants for rocket, cannon, and small arms ammunition. BAAP's production facilities and support facilities were placed on standby status in March 1975.

During the plant's period of active operation, various chemical materials were produced, and the associated materials and manufacturing byproducts disposed of through practices both common and acceptable at the time. The materials included acids, nitroglycerin, and NC. Approximately 1,000,000 pounds (lb) of NC fines are still being stored at BAAP.[13]

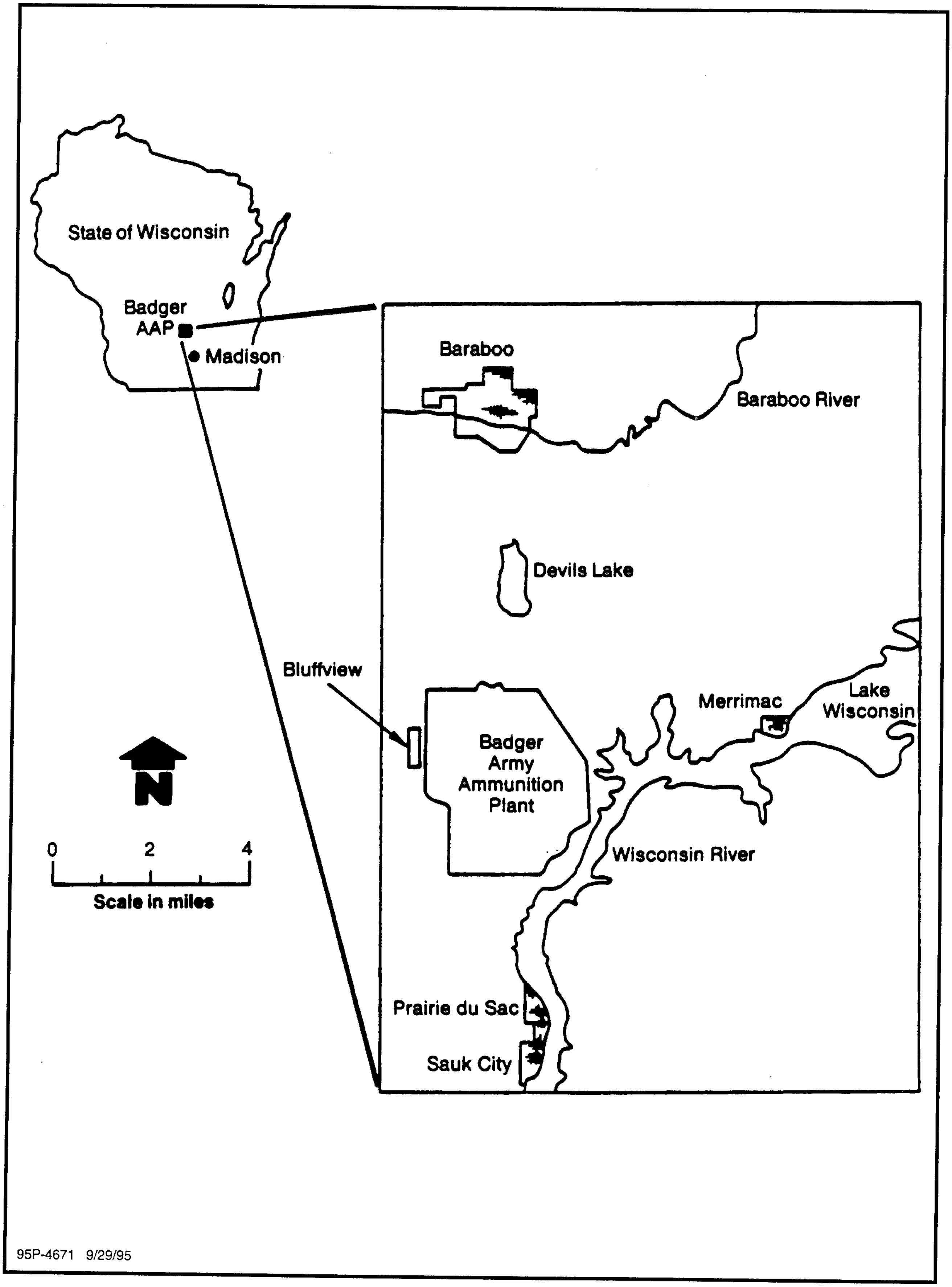

FIGURE 1-1 LOCATION OF BAAP IN WISCONSIN

1.3 COMPOSTING OF NC FINES HAZARDS ANALYSIS RESULTS

Due to the reactive nature of NC fines, particularly when dry, an assessment of the level of NC fines that could be handled safely during the composting process was needed. To accomplish this, USAEC has conducted testing and evaluation of the reactivity of NC fines compost. Compost mixtures were developed based upon characteristics of NC fines and of amendment materials available in the vicinity of the Radford Army Ammunition Plant (RAAP), the Army's current NC production facility. RAAP conducted reactivity testing to establish reactivity levels. NC fines loading rates between approximately 10 and 35% at 30% moisture meet the safety requirements from the RAAP hazard analysis and are within the moisture levels included in the BAAP composting study.[8]

Based on these positive findings, a conceptual level analysis of the use of composting technology for the treatment of NC fines was conducted. The composting process is anticipated to yield a nonreactive soil amendment suitable for beneficial uses. NC fines loading rates and treatment periods were based on previous composting studies[8] and the hazard analysis conducted by RAAP. The loadings indicated by the RAAP hazards analysis to be nonreactive at moisture levels acceptable for composting were used in the conceptual level development and cost analysis. Using an NC fines throughput of 1,650 lb/day (wet basis) and a 35% NC fines loading at 30% moisture, the total 20-year project cost, including contingency, was estimated to be $6,532,000. This corresponds to a cost of $1,000/ton of NC fines, or $310/yd^3 of NC fines.

1.4 OBJECTIVES

The overall objective of this Task Order is to prepare a report summarizing the regulatory requirements associated with composted NC fines disposal and evaluating the feasibility, including costs, of various end-use options. End-use options to be considered include the following:

- Land application (with crop harvesting) by the installation.
- Providing local farmers with compost as a soil amendment.
- Landfilling the finished NC fines compost.

The following overall approach was used in conducting this evaluation:

- A site visit to BAAP was conducted on 28 February 1995. During this visit, meetings were held with BAAP personnel to discuss the NC production process. A site tour was conducted to evaluate on-site land use and availability; appropriate mapping and other information was obtained or requested. Site visit notes are provided in Appendix A.

- Potentially applicable regulatory information was obtained and reviewed. This information included federal and state (Wisconsin) solid waste and land application regulations, as appropriate.

- Projected finished compost quantities were estimated based on the quantity of NC fines product in storage at BAAP and the general operating parameters for NC fines composting, as established in previous projects. [7,8,12]

- A conceptual evaluation of each disposal option was conducted, considering quantities, regulatory analyses, and local conditions. Location-specific information will be used in conjunction with the estimated compost chemical composition and regulatory constraints to determine appropriate compost application rates for each end-use option. Land acreage requirements and subsequent costs associated with each option will be calculated.

Since any evaluation of these options will be to some extent location-specific, two test cases were selected for this evaluation: (1) Badger AAP in Baraboo, Wisconsin, which historically produced nitrocellulose; and (2) Radford AAP in Radford, Virginia, which currently produces nitrocellulose. This report addresses BAAP, whereas the analysis of compost disposal for RAAP is presented in a separate document.

SECTION 2
COMPOST DISPOSAL OPTIONS SELECTION CRITERIA

Previous work has shown that composting of NC in soils is technically achievable.[7,8] Recently, an economic analysis has shown that composting of NC fines is an economically feasible treatment alternative.[12] The composting process will yield a beneficial soil amendment that will be available for various end-uses.

Land application of compost to aid in reclamation of land disturbed by mining operations is also a usable alternative in many cases. However, surface mining operations do not exist within 100 miles of BAAP; therefore, land application of compost for mining reclamation was not considered. This section describes the criteria used in selecting potential sites for various management options. The criteria present possible regulatory and engineering limitations investigated to determine the feasibility of using available land for compost application.

2.1 LAND APPLICATION BY THE INSTALLATION

In this alternative, BAAP will use the compost, as a beneficial soil amendment, on available agricultural land at the installation. The nitrogen-rich compost will be applied to land used for agricultural purposes. The crops planted on these sites will be harvested to prevent nitrogen accumulation in the soil and potential migration into groundwater. This option will require the installation to initiate and maintain a full-scale farming operation. The farming operation will consist of activities such as plowing, seeding, tilling, applying the compost, and harvesting the vegetation. The harvested vegetation would be given away at no cost or income to the installation.

The feasibility and acceptability of land application is directly determined by the characteristics of the material to be applied and the characteristic of the land in the application area. A preliminary evaluation of the availability of suitable land within the BAAP facility was conducted.

The following criteria were used in delineating land within the installation that is potentially suitable for compost land application with subsequent crop harvesting:

- Federal and state regulatory constraints on application rates based on compost chemical constituents were used in conjunction with crop uptake data and estimated compost quantities to determine the required acreage for land application.
- Current land uses were determined from information supplied by BAAP during the site visit.
- Potentially available acreage was approximated from BAAP installation land use maps.
- Slope requirements for land application were determined from federal and state regulations.
- Slopes of potentially available land were determined from topographical maps.
- Applicable buffer zones for application areas were determined from federal and state regulations.
- Hauling distances and spreading/harvesting costs were approximated based on available information.

2.2 SUPPLY OF COMPOST FOR AGRICULTURAL LAND APPLICATION

In this alternative, the compost will be applied to off-site locations or at the installation on land leased by the local farmers. The installation will transport the finished compost to the farmer's location of application, at no cost to the farmer. The farmers will use the compost as a beneficial soil amendment to be applied to the land as a nitrogen source for vegetation. The farmers will incur all farming operations costs. Application to on-site land by local farmers would be preferable to off-site farm sites because the installation could more easily monitor the area of application for nitrogen accumulation in the soil and potential migration to groundwater.

The following criteria were used in delineating land in the vicinity of BAAP that is potentially suitable for land application to farming areas as a soil amendment:

- Federal and state regulatory constraints on application rates based on compost chemical constituents were used in conjunction with crop uptake data and estimated compost quantities to determine the required acreage for farming land application.

- Areas currently being used for agricultural purposes were determined from available information.

- Prevalent agricultural crops for the BAAP vicinity were determined from agricultural agencies.

- Potentially available acreage was determined from available information.

- Slope requirements for land application were determined from federal and state regulations.

- Slopes of potentially available land were determined from topographical maps.

- Applicable buffer zones for application areas were determined from federal and state regulations.

- Hauling distances were approximated based on information from local land use maps.

2.3 LANDFILLING

Landfilling of the finished compost may be necessary because of a lack of demand by local farmers for the compost or the inability of the installation to apply it on-site. In this alternative, the finished compost would be deposited in a landfill for final disposal. This alternative would not take advantage of the possible beneficial use of the compost as a soil amendment.

The following criteria were used in evaluating landfilling as a disposal option for NC fines compost:

- The applicability of landfilling finished compost were determined by federal and state regulations.

- Hauling distances were approximated from local maps.

SECTION 3
REGULATORY SUMMARY

3.1 INTRODUCTION

A federal and state regulatory review was conducted to determine issues that may impact management and disposal options for NC compost. Hazardous and solid waste regulations were examined with respect to specific applications of the finished compost.

3.2 REGULATORY STATUS OF FINISHED NC COMPOST

NC has not been produced at BAAP since 1975. However, NC fines from prior production operations are stored under water in tanks at the facility. The Army does not consider the NC fines to be a waste, but rather a recoverable and reusable material.

If NC fines were considered to be waste materials, it would be necessary to determine their potential status as hazardous wastes under Resource Conservation and Recovery Act (RCRA) Subtitle C in order to evaluate management options for the compost. If they were considered hazardous wastes, a key distinction would be that between listed (K, F, P, or U) wastes and characteristic wastes (D). If the NC fines were listed wastes, their subsequent treatment, disposal, or other management would have to meet hazardous waste management requirements, or the material would have to be specifically delisted. If the materials were RCRA hazardous wastes, they would have to be treated such that they no longer exhibit the RCRA characteristic, at which point they could be managed as nonhazardous wastes.

Based on information developed in this project, NC fines at BAAP are not considered to be RCRA Subtitle C hazardous waste. Production of NC at BAAP ended prior to the start of the RCRA program. In addition, EPA has made the determination that nitrocellulose does not pose a toxicity hazard that warrants regulation, as summarized in the Nitrocellulose Health Advisory document.

Although EPA's original Listing Background Document, Explosives Industry,[16] indicates that sludges from explosives manufacturing and processing may be listed on the basis of reactivity, the Army has successfully argued that ND fines are not listed wastes.[17] As noted previously, the Army does not , in fact, consider these materials to be wastes in their present form.

Although NC fines are not considered to be a waste by the Army, future management options that will result in their being disposed of as a waste (such as landfilling) may need to consider their classification as RCRA characteristic wastes.

NC fines do not exhibit the RCRA characteristics of ignitability, corrosivity, or toxicity. Although NC fines can be reactive under specific conditions, particularly when dry, the finished compost mixtures will not be reactive because adequate moisture will be provided and the NC fines will have been treated to levels determined to be nonreactive in the RAAP Hazards Analysis. In particular, final NC concentrations will conservatively be less than 10% NC.[12] Results of the RAAP testing indicated that at concentrations less than 12% NC, NC fines compost was nonreactive at all moisture levels. Results of the RAAP hazards analysis were summarized in the *Composting of Nitrocellulose Fines - Hazards Analysis* report.[12]

The finished compost materials to be applied to land, which are a mixture of NC fines and amendments, may be considered a solid waste because federal regulations (40 CFR 261.2) state that a solid waste is any recycled material that is "used to produce products that are applied to or placed on the land or are otherwise contained in products that are applied to or placed on the land...". Thus, prior to land application, it may be necessary to demonstrate that the finished NC compost is not hazardous and does not exhibit the RCRA characteristic of reactivity. Federal regulations (40 CFR 261.23) describe the properties of solid wastes that exhibit the characteristic of reactivity. These properties include:

- Normally unstable and readily undergoes violent change without detonating.
- Reacts violently with water.
- Forms potentially explosive mixtures with water.

- When mixed with water, generates toxic gases, vapors, or fumes in a quantity sufficient to present danger to human health or the environment.

- Is a cyanide- or sulfide-bearing waste that, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment.

- Is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

- Is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

- Is a forbidden explosive, as defined in 49 CFR 173.51; or a Class A explosive, as defined in 49 CFR 173.53; or a Class B explosive, as defined in 49 CFR 173.88.

There are no prescribed analytical methods in the federal or state regulations to determine whether a waste has these reactive properties; however, laboratory tests can be designed to demonstrate their presence or absence. Therefore, such laboratory-designed tests can be used to verify that the final NC compost mixture is not reactive and can be disposed of as a nonhazardous solid waste. Reactivity tests that are commonly used include Critical Diameter, Bureau of Mines (BOM) Zero Gap, and Deflagration to Detonation Transition (DDT). Therefore, it is assumed for this project that NC-fines compost will not be a RCRA listed or RCRA characteristic waste.

Review and comparison of the state and federal regulations indicates that this criteria for identifying hazardous wastes are equivalent. Therefore, a solid waste considered nonhazardous under the federal regulations would be considered the same under Wisconsin regulations. Because it is expected that the finished compost will be considered a nonhazardous solid waste under the federal regulations, it is also expected to be considered the same under the state regulations. The following subsections contain a discussion of applicable or potentially applicable regulations for the land application or landfilling of finished NC compost in Wisconsin.

3.3 WISCONSIN REGULATIONS

3.3.1 Disposal of Finished NC Compost in a Sanitary Landfill

The Wisconsin regulations for landfilling of nonhazardous solid waste do not contain any special provisions for finished compost materials. However, in the Wisconsin Administrative Code of Regulations under the Department of Natural Resources (WAC NR) 506.09, it is stated that only the waste types and sources listed in the landfill's plan of operation may be accepted for disposal. If the NC-finished compost is not considered as one of the acceptable waste types or sources, then the landfill would need to submit a request to the Department of Natural Resources (DNR) for authorization to accept additional waste types. This submittal would include, at a minimum, the following information:

- Detailed physical and chemical characteristics, including percent solids and the results of the paint filter test.
- The volume of waste to be disposed of on a daily and yearly basis.
- The source of the waste and a description of the processes that generated the waste.
- The duration of disposal.
- Special handling and disposal procedures.

In summary, it appears that the nonhazardous finished NC compost can meet sanitary landfill permitting requirements in the State of Wisconsin. Although there may be some additional data requirements, landfilling can be a viable means of finished NC compost disposal.

3.3.2 Land Application of Finished NC Compost

The WAC DNR regulations for land spreading of solid waste can be found in WAC NR 518. Additional regulations for land spreading of industrial liquid wastes, by-product solids, and sludges can be found in WAC NR 214.17 and 214.18. However, the latter regulations do not appear to be applicable to the finished NC compost materials when considering the following definitions of liquid waste, by-product solids, and sludge cited in WAC NR 500.03:

- "Liquid waste" means process wastewater and waste liquid products, including silage leachate, whey, whey permeate, whey filtrate, contact cooling water, cooling or boiler water containing water treatment additives, and wash water generated in industrial, commercial and agricultural operations that result in a point source discharge to a land treatment system.

- "By-product solids" means waste materials from the animal product or food processing industry including, but not limited to, remains of butchered animals; paunch manure; and vegetable waste materials, such as leaves, cuttings, peelings and actively fermenting sweet corn silage.

- "Sludge" means the accumulated solids generated during the biological, physical or chemical treatment, coagulation or sedimentation of water or wastewater.

The compost mixture, as proposed in the *Composting of Nitrocellulose Fines - Hazards Analysis* report, does not meet the characteristics of any of the above mentioned categories. However, if the amendment mixture would be revised to include vegetable matter, then the compost may meet the description of by-product solids. Regulations contained in WAC NR 214.17 and 214.18 may then need to be considered. However, for the current proposed compost mixture, the most applicable regulations are contained in WAC NR 518, Land Spreading of Solid Waste.

In WAC NR 518.06, it is stated that "No person may establish, construct, operate or maintain a solid waste land spreading facility without first obtaining written approval from the department [DNR] of a solid waste land spreading plan..." The plan must demonstrate to the DNR that the proposed facility will comply with all the location and performance standards unless an exemption is granted. The facility cannot be located within the following areas:

- Within 100 feet of any navigable body of water.

- Within 5,000 to 10,000 feet of an airport runway where a potential bird hazard to aircraft would be created by the facility. This is applicable only where a facility is used to dispose putrescible waste.

- Within 1,000 feet of public water supply wells or 200 feet of private water supply wells.

- Within 500 feet of any residence, unless written consent is obtained from the resident. This distance may also be reduced for the residence of the property owner on whose land solid waste is spread.

The performance standards indicate that a land spreading facility cannot be operated in an area where there is a reasonable probability that the facility will cause:

- A significant adverse impact on wetlands.
- A significant adverse impact on critical habitat areas.
- A detrimental effect on any surface water.
- A detrimental effect on groundwater quality.
- The migration and concentration of explosive gases in any structures or in the soils or in air at or beyond the facility property boundary, in excess of 25% of the lower explosive limit for such gases at any time.
- The emission of any hazardous air contaminant exceeding the limitations for those substances contained in NR 445.03, Control of Hazardous Pollutants.

The Solid Waste Land Spreading Plan shall include a waste characterization, a waste use determination, a description of facility characteristics, and information on facility design, development, and operation. The waste characterization will include a detailed description and analysis of the finished NC compost materials. Specifically, the following minimum information is required:

- The sources, processes, or treatment systems from which the wastes originate, including a list of all chemicals added and associated material safety data sheets (MSDS).
- Waste pretreatment or waste processing techniques used prior to land spreading.
- The volumes of solid wastes to be spread, stored, or disposed of.
- Physical characteristics of the waste material, including solids fraction and organic fraction.
- A priority pollutant scan of the waste material.
- pH of the waste material.
- Nutrient content, including Kjeldahl-nitrogen, ammonia-nitrogen, nitrate and nitrate-nitrogen, phosphorous, and potassium.
- Metals content.

- Salt content.

- Biological populations.

- Leach tests that represent the anticipated field conditions shall be performed on the waste material, on the soil type at the proposed facilities, and on a mixture of the two.

The waste use determination will include an assessment and analysis of data, including conclusions drawn concerning the potential benefits and adverse effects of the land spreading program. This assessment shall include information showing that the waste has value as a soil conditioner or fertilizer, or that it will not cause a detrimental effect to public health, welfare, or the environment.

Facility characteristics described in the Solid Waste Land Spreading Plan will include descriptions of the facility location, description of contracts or agreements covering the use of the land, land uses at and around the facility, regional geology and hydrogeology, well locations within ½ mile of the facility, crops to be grown or dominant vegetation at the facility, soil test results from samples collected at the facility (soil analyzed for pH, organic matter, available phosphorous, available potassium), soil additives to be used, and identification of the nearest floodplain.

The description of the facility design, development, and operation in the Solid Waste Land Spreading Plan will include the following: provisions for interim waste storage and disposal when normal land spreading facilities are unavailable; waste transportation details; proposed maximum rates of application, both annual and cumulative, for nitrogen, arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, and other heavy metals, in accordance with WAC NR 204 (Municipal Sludge Management Regulations), Technical Bulletin No. 88, and any other appropriate technical literature; proposed monitoring; and proposed recordkeeping and reporting procedures.

Finally, WAC NR 518.07 contains specific requirements for land spreading operation and monitoring. The facility must be operated in accordance with the approved Solid Waste Land Spreading Plan. In addition, only approved waste types can be disposed of at the facility. The waste materials must be plowed, disced, or otherwise incorporated into the soil matrix, as specified in the approved plan. A vegetative buffer strip must be maintained between the facility and any navigable water. Waste cannot be placed in areas containing ponded or standing water. Waste materials with significant pathogenic bacteria must be properly stabilized before placement. Food chain crops grown on solid waste land spreading facilities that have received waste applications containing pesticides or persistent organic materials may not be marketed or used for human or animal consumption unless the crops meet all applicable contaminant levels, as established by the U.S. Food and Drug Administration or the State of Wisconsin.

The maximum one-time and cumulative loading rates of cadmium and other heavy metals must comply with WAC NR 204, Technical Bulletin No. 88, and any other appropriate literature. WAC NR 204.07(3) contains maximum application rates for sludge based on crop nitrogen needs; types of crops grown at the land application area; amounts of cadmium, other heavy metals, polychlorinated biphenyls (PCBs), and other pollutants contained in the sludge. These requirements would also apply to finished NC compost materials and are provided in Appendix B to this report.

Technical Bulletin No. 88, *Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin*, discusses factors that are considered in determining sludge application rates to agricultural soils, particularly with respect to applied nitrogen, phosphorus, potassium, and heavy metals. A copy of Technical Bulletin No. 88 is provided in Appendix C.

Monitoring reports must be submitted to DNR on a frequency specified in the approved Solid Waste Land Spreading Plan. The monitoring reports will contain the following information:

- The amount of solid waste applied in tons per acre on a dry-weight basis.
- The estimated mineralization rate of the applied nitrogen applied in pounds per acre on a dry-weight basis.
- The amount of cadmium applied in pounds per acre on a dry-weight basis.
- The total amount of each metal specified by DNR applied in pounds per acre on a dry-weight basis.
- Other information required by DNR as part of the approved plan.

- Description of adverse environmental, health, or social effects that occurred due to disposal.

- Description of any actions not in conformance with the approved plan.

In summary, the State of Wisconsin has promulgated very specific regulations concerning the land application of solid wastes. Review of these regulations indicates that there does not appear to be any impediments for use of this disposal method for the finished NC compost. Therefore, land application of finished NC compost can be a viable means of disposal.

SECTION 4

COMPOST DISPOSAL ALTERNATIVES

Several end-use alternatives for the finished NC fines compost were evaluated using the criteria discussed in Section 2. Results of this evaluation are presented in this section. End-use alternatives evaluated included:

- Land application (with crop harvesting) by the installation.
- Providing local farmers with compost as a soil amendment.
- Landfilling the finished NC fines compost.

Federal and state regulations governing the disposal alternatives of the finished NC fines compost were described in Section 3. All of the proposed end-use alternatives may be accomplished in compliance with federal and Wisconsin regulations, with some restrictions.

Land application of NC fines compost will provide plant nutrients for crops and will add humus to the soil. Increasing the organic content of a soil increases its ability to hold plant nutrients and moisture. An immediate benefit of compost land application is its plant nutrient content, particularly in terms of nitrogen. However, to avoid contamination of surface and groundwater, it is important that applied plant nutrients, particularly nitrogen, do not exceed crop requirements and other losses. This is true for commercial fertilizer application as well as compost application.

When NC fines compost is applied to land, the nitrogen it contains will reach some combination of the following fates:

- NH_3 volatilization to the air.
- Nitrification and leaching to groundwater as NO_3.
- Nitrification and denitrification, with nitrogen gas (N_2) volatilization to the air.
- Plant uptake of NH_3 and NO_3.

In addition to concern for the fate of nitrogen, metals may also need to be considered during compost land application processes. Generally, regulatory loading rates for copper, nickel, and zinc are based on the potential to decrease crop yields, particularly for leafy green vegetables. Lead loading rates are generally specified to reduce chances for direct ingestion by animals. Lead is not taken up by vegetation unless it is present at very high concentrations. Cadmium can accumulate in vegetation without causing crop damage. Therefore, cadmium loading rates are set to prevent entrance into the mammalian food chain where it could lead to kidney disorders.[14]

In general, the amount of NC fines compost that can be applied to the land is determined by constituent (i.e., various metals, phosphorus, and nitrogen) loadings. Specific constituents determining application rates are identified by individual states. As discussed in Section 3, Wisconsin regulations dictate levels of metals and nitrogen that may be applied to land. Significant concentrations of metals would not typically be found in either the NC fines or the amendments used in the composting procedure. However, both the proposed amendments and NC fines are significant sources of nitrogen. Therefore, land application of the compost will likely be a nitrogen-limited process. For comparison, the mean total nitrogen in typical wastewater sludge is 3.9%.[15] The nitrogen content in NC is up to 14.14%. Prior to land application, analyses should be conducted to verify these assumptions.

Appendix D shows the equations and calculations used to estimate the amount of finished compost that can be applied per acre of land based on nitrogen limitation. These calculations were based on producing approximately 450 tons/year of finished compost (on a dry basis). This compost production rate was selected because it allows for treatment of the approximately 1,000,000 lb of NC fines (dry basis) in a feasible project life of about 2 years. This production rate would require a facility of approximately the same size as that described in the *Composting of Nitrocellulose Fines - Hazards Analysis* report.[12] Therefore, the composting equipment and pre-fabricated structure could be used at BAAP for 2 years, then transported to RAAP for the remainder of the service life. The following assumptions were used for the calculations of land requirements:

- All the nitrogen contributed by the NC fines is nitrate-nitrogen (NO_3-N).
- All the nitrogen contributed by the amendments is ammonia-nitrogen (NH_4-N).

- A volatilization factor of 0.5 was applied to ammonia because of the surface-applied method of application. This means that one-half of the ammonia present in the finished compost will be volatilized during land application.

- No organic nitrogen exists in the final compost.

- The annual nitrogen uptake by vegetation was assumed to be 210 lb/acre (based on Kentucky Bluegrass, chosen because its nitrogen uptake rate is near the average for grass species). Actual nitrogen uptake will vary depending on the vegetation.

- Vegetation will be harvested annually from the application area.

The amount of nitrogen that can be applied to the land will depend in large part on the nitrogen uptake rate of the vegetation to be planted. The net amount of nitrogen (after volatilization) that is applied to the land should equal the amount of nitrogen taken up by the vegetation and subsequently removed from the land through harvesting. If the crop is not harvested, the nitrogen from the vegetation would return to the soil. The land area needed for compost application is, therefore, calculated by setting the nitrogen losses by all mechanisms, which includes the vegetation annual nitrogen uptake rate, equal to the amount of nitrogen to be applied to prevent a net nitrogen accumulation in the soil. Application of nitrogen in excess of that which can be removed by volatilization and plant uptake will be available for leaching to groundwater, generally as nitrate-nitrogen. NO_3-N is regulated in drinking water under the Safe Drinking Water Act (SDWA) with a maximum contaminant level (MCL) of 10 mg/L NO_3-N. Many agencies restrict NO_3-N in the percolation from application areas to the SDWA MCL of 10 mg/L.

As given in Appendix D, the amount of compost that could be applied annually at the specified nitrogen uptake rate is estimated to be 1.4 tons of compost/acre. Based on this application rate of 1.4 tons/acre, approximately 320 acres/year will be required for final compost disposal. As stated previously, the number of acres will vary based on the vegetation assumed to be grown. For example, alfalfa has a nitrogen uptake value of up to 600 lb/acre compared with the specified rate of 210 lb/acre for Kentucky Bluegrass. Therefore, if alfalfa is planted instead of Kentucky Bluegrass, more nitrogen will be utilized by the vegetation and more compost may be applied per acre. End-use alternatives for this compost are discussed in the following subsections.

4.1 LAND APPLICATION BY THE INSTALLATION

Land application of the NC fines compost as a possible end-use alternative would be acceptable under the Wisconsin regulations but would require permitting and would be subject to restrictions. As discussed in Subsection 3.3.2, land application would require a Solid Wasteland Spreading Plan to be submitted to the DNR for written approval. Without the written approval of the plan from DNR, land application would not be permitted and the NC fines compost would have to be landfilled. Certain restrictions would also apply to land application, as outlined in Subsection 3.3.2.

Land application of the finished NC fines compost at the installation would consist of application of the compost and the planting and harvesting of vegetation to remove the nitrogen contributed by the compost from the site. The type of vegetation to plant would be influenced by the following factors:

- Vegetation suitable for the particular climatic region and soil specifications.
- The rate of nitrogen uptake of the vegetation to be planted.
- Maintenance of the land to promote growth of the vegetation.

Planting and harvesting would have to be conducted periodically to prevent a net nitrogen accumulation in the soil.

Available land within the installation boundaries was identified through land usage maps of the installation. Topography of the area was also taken into account to ensure that the compost application equipment can be safely operated at the slopes present on the specified land and that runoff and erosion can be minimized to prevent nitrogen contamination of surface water. The installation has approximately 1,430 acres of crop land and 2,850 acres of pastures. This acreage is in excess of the land requirements calculated in Appendix D. Although all of this land may not be available for use due to various structures and roads within the area, it seems likely that the required 320 acres will be available.

The costs associated with this disposal alternative would include:

- Costs and fees associated with the preparation and submittal of a Solid Waste Land Spreading Plan to the DNR for approval.
- Transportation of the finished NC fines compost.
- Costs associated with the preparation and submittal of annual monitoring reports to DNR.
- Purchase or lease of equipment necessary for application of the compost and for the planting and harvesting of the vegetation.

4.2 PROVIDING LOCAL FARMERS WITH COMPOST AS A SOIL AMENDMENT

According to Wisconsin regulations, the finished NC fines compost could be used by local farmers as a nitrogen source for crop growth for animal or human consumption if the crops meet all applicable contaminant levels as established by the U.S. Food and Drug Administration or the State of Wisconsin. The compost could also be supplied to local municipalities or counties for use in recreation areas. The same vegetation constraints would exist for application by local farmers that exist for application of compost on the installation.

The amount of land currently being used for agricultural purposes within the counties surrounding the installation was identified. The installation is located in Sauk County. Counties in proximity to the installation include Columbia, Dane, and Iowa. Available agricultural statistics for the four-county area are presented in Table 4-1. As presented in Table 4-1, acreage well in excess of the land requirements calculated in Appendix D exists in the vicinity of the installation. Based on the large availability of agricultural land in the vicinity of BAAP, it seems likely that the required acreages could be obtained.

Although the Wisconsin regulations have no specific slope restrictions for application of solid waste, it is assumed that the slope of much of this land would not pose a logistical problem because the land is currently being used for agricultural purposes. However, slopes will be considered on an individual basis to minimize runoff and erosion potential.

Table 4-1

BAAP Area Agricultural Statistics, 1994 Statistics

County	Number of Farms			
	Number of Farms	Average Size of Farms (acres)	Land in Farms (acres)	County Rank within the State for Land in Farms
Columbia	1,660	213.9	355,000	17
Dane	3,020	194.3	584,000	2
Iowa	1,520	261.2	397,000	16
Sauk	1,570	234.4	368,000	9

Source: *Wisconsin 1995 Agricultural Statistics*, Wisconsin Agricultural Statistics Service.

The constraints associated with land application of the compost at the installation also apply to local farmers. According to Wisconsin regulations governing land application of solid wastes, the installation and the farmers using the finished NC fines compost would be required to enter into an agreement concerning annual monitoring of the land on which the compost would be applied. The installation would bear the responsibility for fulfilling all monitoring requirements and producing annual monitoring reports as required by DNR.

The costs associated with this disposal alternative would include:

- Transportation of the finished NC fines compost from the installation to the farmers.
- Costs and fees associated with the preparation and submittal of a Solid Waste Land Spreading Plan to the DNR for approval. It is assumed that these costs and fees would be borne by the installation.
- Costs associated with the preparation and submittal of annual monitoring reports to DNR. It is assumed that these costs would also be borne by the installation.

4.3 LANDFILLING THE FINISHED NC FINES COMPOST

Landfilling of the finished NC fines compost would be an acceptable disposal alternative under the Wisconsin regulations. Additional material characterization information (as presented in Subsection 3.3.1) may be required by the landfill prior to acceptance of the finished NC fines compost. Landfilling finished compost would be less desirable than the previously discussed alternatives because the potential benefits of the NC fines compost would not be realized. However, it may be possible to supply compost to landfills as a cover material for capped areas. This would represent a beneficial use for the product and would eliminate the costs associated with tipping fees. The costs and restrictions conservatively included in this report are for landfill inclusion rather than for cover purposes.

The costs associated with landfill disposal would include:

- Transportation of the NC fines compost to the landfill facility.

- Additional material characterization information if the NC fines compost is not considered one of the listed wastes already accepted by the landfill facility.

- Landfill tipping fees.

SECTION 5
ECONOMIC ANALYSIS

Regulatory and logistical constraints associated with implementing various end-use alternatives were described in Sections 3 and 4. In this section, potential costs associated with the specified alternatives are developed. This analysis is intended to evaluate and compare the relative costs of land application, either by the BAAP installation or by area farmers, with the costs associated with landfilling the finished compost. The following alternatives will be analyzed:

- Land application (with crop harvesting) by the installation.
- Providing local farmers with compost as a soil amendment.
- Landfilling the finished NC fines compost.

5.1 METHODOLOGY AND ASSUMPTIONS

Costs for the specified end-use alternatives were developed using conventional cost-estimating procedures. Unit prices were obtained from the U.S. Army Corps of Engineers (USACE) Construction Equipment Ownership and Operation Expense Schedule, the *DataQuest Bluebook*, and prevailing usages for Richmond, Virginia, as presented in Table 5-1. The major items in the cost estimate include:

- Land Application Process
    - Spreading
    - Planting
    - Cutting
    - Raking
    - Baling and Loading
- Crop seed (land application)
- Transportation of compost and/or crop
- Landfill tipping fees

Table 5-1

Unit Costs for Land Application at BAAP

Item	Cost ($)*
Transportation	0.45 /ton mile
Seeds	50/acre
Compost spreading	13.75/acre
Plant crop	10.86/acre
Cut crop	14.77/acre
Rake, two times	27.23/acre
Bale and load crop	10.30/acre

*Unit costs were obtained from the following references:

USACE Construction Equipment Ownership and Operation Expense Schedule.
DataQuest Bluebook.
The prevailing wage rates for Richmond, Virginia, were used.

Note: Costs are presented on a $/acre basis because the number of acres needed will be dependent on the type of vegetation grown on the land.

In the development of the economic analysis, the following assumptions were made:

- Costs for permitting and regulatory compliance monitoring are not included in this analysis. Although there will be costs associated with these items, they are difficult to accurately assess at this time.

- No costs or income to the installation will result from transfer of the finished compost to area farmers.

- A total of approximately 450 tons/year of finished compost, on a dry basis, will be available based on a processing rate of 450,000 lb/year of NC fines on a dry basis for 2 years. This conservatively assumes no mass loss during composting.

- Equipment needed to spread the compost, till, and plant and harvest crops will be leased in the land application scenario by the installation.

- In the local farm application scenario, it is assumed that the farmer will apply the compost and plant and harvest the crops. Costs associated with these operations are not included in this alternative.

- All costs are in 1995 dollars.

- Harvested crops are assumed to be distributed to users at no cost or income to the installation through a public distribution point located at or adjacent to the BAAP installation.

- A 2-year project life was assumed. Assuming a facility size equivalent to that used in the Conceptual Design presented in *Composting of Nitrocellulose Fines-Hazards Analysis*, the approximately 1,000,000 lb of NC fines currently at BAAP can be processed in about 2 years. Two years is a reasonable period for the treatment and disposition of the finished compost. By using the same facility size as that used in the conceptual layout of the RAAP treatment facility, the necessary pre-fabricated structures and equipment could be used to complete the treatment at BAAP and then be used at the RAAP installation.

- Transportation costs of finished compost and harvested crop are estimated on a loaded mile basis (cost/ton mile).

- Unit costs associated with agricultural operations are priced on a per acre basis.

5.2 CONTINGENCY

A contingency factor (generally as a percentage of total anticipated expenditure) is conventionally added to various types of cost estimates to allow for unknown and unforseeable factors or changes that may develop. Costs in this report are presented with a 15% contingency factor.

5.3 PROJECT FINANCING

It has been assumed that funds would be obtained through government appropriations on a fiscal-year basis. Therefore, no costs associated with project financing are included.

5.4 RESULTS FOR END-USE ALTERNATIVES

This subsection presents potential costs associated with each end-use alternative.

5.4.1 Land Application by the Installation

Costs associated with this alternative are:

- Costs of transporting the finished NC fines compost to the application area.
- Costs associated with compost spreading, tilling, seeding, and harvesting operations. Unit costs are calculated on a per acre basis in accordance with information available for agricultural practices. Unit costs are presented in Table 5-1. These costs include equipment lease and operation and maintenance as well as labor.
- No transportation costs for the harvested crop are included because it was assumed that the crop would be given away by the installation at no cost or profit to the installation.

Estimated annual costs for land application of finished NC fines compost at the installation are presented in Table 5-2. Within the previously stated constraints, the cost of this alternative is

Table 5-2

Estimated Annual Costs for Land Application by the Installation

Item	%Markup	Amount	Unit Cost	Cost ($/year)
Transportation		640 tons	$0.45	$720
Seed		320 acres	$50.00	$16,000
Compost Spreading		320 acres	$13.75	$4,400
Seeding Crop		320 acres	$10.86	$3,480
Cut Crop		320 acres	$14.77	$4,730
Rake Crop		320 acres	$27.23	$8,715
Bale and Load Crop		320 acres	$10.30	$3,300
First Subtotal				**$41,345**
Engineering, Procurement, Administrative, and Legal	@ 15%			$6,200
Contractor Markup and Profit	@ 10%			$4,130
Second Subtotal				**$51,675**
Contingency	@ 15%			$7,750
Total				**$59,400**

Assumptions:

Transportation costs are presented in $/ton mile.

The compost will be transported an average of 2.5 miles to application site.

estimated to be $59,400/year. This corresponds to a cost of $90/ton of finished compost (wet basis) or $260/ton of stored NC fines (dry basis). The cost per ton of compost is less than the cost per ton of stored NC fines because the compost unit cost includes the mass of added amendments and water and is, therefore, based on a larger mass of material. The costs are for finished compost disposition only and will be in addition to treatment costs presented in the *Composting of Nitrocellulose Fines - Hazards Analysis* report.[12]

5.4.2 Providing Local Farmers with Compost as a Soil Amendment

Costs associated with this alternative are:

- Costs of transporting the finished NC fines compost to the local farms.
- No costs are included for agricultural operations because they are assumed to be performed by the individual farmer.
- No costs are included for crop disposition because crop disposition is assumed to be handled by the individual farmer.

Estimated annual costs for supply of NC fines compost to local farmers for land application as a soil amendment are presented in Table 5-3. Within the previously stated constraints, the cost of this alternative is estimated to be $8,300/year. This corresponds to a cost of $20/ton of finished compost (wet basis) or $40/ton of NC fines (dry basis). The cost per ton of compost is less than the cost per ton of stored NC fines because the compost unit cost includes the mass of added amendments and water and is, therefore, based on a larger mass of material. The costs are for finished compost disposition only and will be in addition to treatment costs presented in the *Composting of Nitrocellulose Fines - Hazards Analysis* report.[12]

Table 5-3

Estimated Annual Costs for Providing Compost to Local Farmers for Land Application

Item	%Markup	Amount	Unit Cost	Cost ($/year)
Transportation		640 tons	$0.45	$5,760
First Subtotal				**$5,760**
Engineering, Procurement, Administrative, and Legal	@ 15%			$860
Contractor Markup and Profit	@ 10%			$580
Second Subtotal				**$7,200**
Contingency	@ 15%			$1,080
Total				**$8,300**

Assumptions:

Transportation costs are presented in $/ton mile.

The compost will be transported an average of 20 miles to application site.

5.4.3 Landfilling

Costs associated with this alternative are:

- Costs of transporting the NC fines compost to the landfill facility. Additional material characterization information if deemed necessary by the accepting landfill.
- Landfill tipping fees.

Estimated annual costs for landfilling NC fines compost are presented in Table 5-4. Within the previously stated constraints, the cost of this alternative is estimated to be $40,500/year. This corresponds to a cost of approximately $65/ton of finished compost (wet basis) or $180/ton of NC fines (dry basis). The cost per ton of compost is less than the cost of stored NC fines because the compost unit cost includes the mass of added amendments and water and, is therefore, based on a larger mass of material. This alternative does not represent a beneficial use of the finished compost. This alternative is more costly than providing the NC compost to local farmers for use as a soil amendment because of the greater transportation distances to landfills from BAAP and tipping fees associated with landfilling. It was assumed that compost would be supplied to area farmers and that the farmers would pay for spreading, planting, and harvesting crops. The costs are for finished compost disposition only and will be in addition to treatment costs presented in the *Composting of Nitrocellulose Fines - Hazards Analysis* report.[12]

5.5 ECONOMIC COMPARISON OF ALTERNATIVES

The estimated annual costs for the three specified end-use alternatives are listed in Table 5-5. The most attractive alternative, based on economic considerations, is supplying of the finished compost to local farmers for use as a soil amendment. This alternative costs significantly less than compost application by the installation because it was assumed that the farmers will bear the costs of compost application, tilling, seeding, and crop harvesting. Land application at the installation, however, may be preferable because the installation will maintain control of the process.

Table 5-4

Estimated Annual Costs for Compost Landfilling

Item	%Markup	Amount	Unit Cost	Cost ($/year)
Transportation		640 tons	$0.45	$5,760
Landfill Tipping Fees		640 tons	$35.00	$22,400
First Subtotal				**$28,160**
Engineering, Procurement, Administrative, and Legal	@ 15%			$4,220
Contractor Markup and Profit	@ 10%			$2,820
Second Subtotal				**$35,200**
Contingency	@ 15%			$5,280
Total				**$40,500**

Assumptions:

Transportation costs are presented in $/ton mile.

The compost will be transported an estimated 20 miles to the landfill.

Table 5-5

Annual Cost Summary of End-Use Alternatives for NC Fines Compost

Alternative	Estimated Annual Cost ($/year)	Estimated Cost per Ton of Finished Compost ($/ton)[a]	Estimated Cost per Ton of Original NC Fines ($/ton)[b]
Land Application by the Installation	$59,400	$90	$260
Supply to Local Farmers for Land Application	$8,300	$20	$40
Compost Landfilling	$40,500	$65	$180

[a]Based on 640 tons/year of compost, wet basis.
[b]Based on 225 tons/year of NC fines, dry basis.

Landfilling is also less costly than application by the installation. However, it may not be a desirable alternative because there is no beneficial use gained from the composted material.

SECTION 6

CONCLUSIONS

Previous work conducted by USAEC has demonstrated that soils containing NC can be treated effectively by composting.[7,8] Recently, it has been shown that NC fines composting may be economically feasible.[12] Composting of NC fines will produce a beneficial soil amendment.

The objective of this report is to summarize the regulatory requirements associated with various end-use options for the finished NC compost and evaluate the technical and economic feasibility of these options. The end-use options that were considered include:

- Land application (with crop harvesting) by the installation.
- Providing local farmers with compost as a soil amendment.
- Landfilling the finished NC fines compost.
- Application for surface mine reclamation.

All of the alternatives, with the exception of surface mine application, were found to be feasible from a logistical and regulatory perspective. The surface mine application scenario was not feasible because no strip mines are located within a 100-mile radius of the BAAP installation. Sections 2 and 3 of this report provided a description of logistical and regulatory constraints for the potential end-use scenarios. In Section 4, these constraints were applied for each scenario to determine the technical feasibility of each alternative. Economic feasibility was considered in Section 5. A basis of 450 tons/year of NC compost production was used. This production rate allows processing of the approximately 1,000,000 lb of stored NC fines in a feasible period of about 2 years. Within the constraints described in Section 4, the annual costs were estimated for each end-use option, as shown in Table 6-1.

Based on the information developed in this report, the following steps should be taken if one of the end-use options for NC compost described is to be implemented:

- Specific sites meeting the technical and regulatory criteria discussed in Section 4 should be selected. For provision of finished NC compost to local farmers, owners need to be contacted and their willingness to participate in a land application program established.

Table 6-1

Annual Cost Summary of End-Use Alternatives for NC Fines Compost

Alternative	Estimated Annual Cost ($/year)	Estimated Cost per Ton of Finished Compost ($/ton)[a]	Estimated Cost per Ton of Original NC Fines ($/ton)[b]
Land application by the installation	$59,400	$90	$260
Providing local farmers with compost as a soil amendment	$8,300	$20	$40
Landfilling the finished NC fines compost	$40,500	$65	$180

[a] Based on 640 tons/year of compost, wet basis.

[b] Based on 225 tons/year of NC fines, dry basis.

- Buffer zones around property perimeters, waterways, and roads should be delineated for specified properties. This would allow for calculation of actual available acreages for land application of the finished NC compost.

- Actual required acreage should be calculated based on the specific crop to be grown on each selected site.

- Compost nonreactivity should be demonstrated prior to implementation of any end-use option.

- Chemical characterization of the compost would be required for the landfill alternative to establish compliance with landfill acceptance requirements. Chemical analysis of the compost would also be required for the land application alternatives to determine nitrogen and metals content to confirm the assumptions made during application rate calculations.

SECTION 7

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APPENDIX A

NOTES ON SITE VISIT TO BAAP

Inter-Office Memorandum

WESTON
MANAGERS DESIGNERS/CONSULTANTS

TO: Bill Lowe

cc: Ed King
Dave Kuczykowski

FROM: Jennifer Picciotti DATE: 14 November 1995

PROJECT: USAEC NC Composting W.O. NO.: 02281-012-011

SUBJECT: Site Visit to Badger Army Ammunition Plant

ACTION:

On February 28, 1995, Ed and I met with John Hansen and Dennis Thurow at the BAAP Administration Building. Dennis proceeded to give us a tour of the facility. From the tour we gained overall land characteristics to be applied to on-site disposal options. The land was mostly rolling hills that could pose application restrictions due to slope and depressions. Most of the land at Badger is leased to the Department of Agriculture which conducts dairy forage research, and to local farmers for corn/small grain crops and cattle grazing. Dennis also gave an estimate of groundwater depth to be 130-150 feet to the upper aquifer and the flow to be mostly north to south with some southwesterly movement.

When we arrived back at the administration building we had a meeting with; the Army Commander Representative, David C. Fordham, P.E., and Olin Engineers Frank E. Wolf, George Shalabi, Lou Unverzagt, Dennis Thurow, and John Hansen. During the course of the meeting, we were informed that Olin had plans to transport the NC fines, which would need to be "cleaned-up" at a cost of approximately $750,000, to their St. Marks facility for reuse, and therefore there may be no need for the compost option. In response we told them that we were conducting a paper feasibility study for USAEC on composting of NC which may be applied to other facilities. Information that was obtained during the meeting included:

- They consider NC fines to be "by-products" and therefore they are not a waste, also that BAAP was pre-RCRA and therefore is grandfathered.

- There are 5 NC productions lines each with a pit, pits B and C are the main storage areas, pit D may contain some small amount, pits E and F do not contain NC fines.

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- There is approximately 1 million pounds of NC to be processed and the last Nitrogen level measured was 12%.

- We requested several items including:

  - As built plans of the pits.

  - Literature to review, including an RI/FS and an annual review for the state.

  - A full site map.

  - To be shown the pits, especially pits B and C.

By the end of the day we had the RI/FS as built plans and site map.

The next morning we were shown the pits by Dennis' assistant and Ed took pictures of both the pits and a nearby field which would be an optimal site for the composting process. The land was large enough for a full scale operation and flat.

We also reviewed the RI/FS and annual report. We found specific groundwater data that shows the depth to be 50-150 ft. BAAP is bordered to the north by Devil's Lake State Park, east and south by farmland and by U.S. Route 12 on the west.

By mid-morning we collected the necessary information, thanked Dennis, John, and David Fordham, and left BAAP. Driving back to the airport we took a car tour of the surrounding area which was mostly dairy farmland.

APPENDIX B

WISCONSIN REGULATION NR 204.07(3)

(3) Application Rates. Sludge may not be applied at loading rates in excess of those listed in this subsection.

(a) The volume of sludge applied annually on a site may not exceed that which is necessary to supply the nitrogen need of the crop to be grown as determined by the analysis of soil samples. The nitrogen recommendations shall be based on the university of Wisconsin soil test recommendations program except as allowed in par. (b).

(b) Sludge may be applied to leguminous crops at a volume sufficient to supply 200 lbs/ac available nitrogen.

(c) No more than 0.5 kg/ha (0.45 lbs/ac) of cadmium may be spread annually on land used for production of tobacco, leafy vegetables or root crops grown for direct human consumption. The amount of cadmium spread annually on land on which other food-chain crops are grown may not exceed the levels listed in Table 1.

Table 1

Time Period	Annual Cd Application Rate kg/ha	lbs/ac
July 1, 1984 to December 31, 1986	1.25	1.11
Beginning January 1, 1987	0.50	0.45

(d) The cumulative amount of cadmium spread on any site may not exceed the levels listed in Table 2.

Table 2

Soil Cation Exchange Capacity (meq/100 g)	Maximum cumulative application Soil pH less than 6.5		Soil pH 6.5 or greater	
	kg/ha	lbs/ac	kg/ha	lbs/ac
Less than 5	5	4.5	5	4.5
5 - 15	5	4.5	10	9
Greater than 15	5	4.5	20	18

(e) The cumulative amount of copper, lead, nickel and zinc spread on any site may not exceed the levels listed in Table 3.

Table 3

	Soil Cation Exchange Capacity (meq/100g)							
	Less than 5		5 - 10		10 - 15		Greater than 15	
	kg/ha	lbs/ac	kg/ha	lbs/ac	kg/ha	lbs/ac	kg/ha	lbs/ac
Lead	500	445	1,000	890	1,500	1,335	2,000	1,750
Zinc	250	225	500	445	750	670	1,000	890
Copper	125	110	250	220	375	335	500	445
Nickel	50	45	100	90	150	135	200	180

(f) Sludge containing concentrations of PCBs equal to or greater than 10 mg/kg (dry weight) shall be incorporated into the soil when applied to land used for producing animal feed, including pasture crops for animals raised for the purpose of producing milk. The department on a case-by-case basis may allow incorporation of the sludge into the soil if it is assured that the PCB content is less than 0.2 mg/kg (actual weight) in animal feed or less than 1.5 mg/kg (fat basis) in milk from animals consuming the feed.

(g) The department may on a case-by-case basis limit or prohibit the land disposal of sludges containing additional pollutants such as, but not limited to, phenolics, pesticides, and persistent organics. Any such limit or prohibition shall be based on waste characteristics, soil cation exchange capacity, type of crop grown, and other factors the department determines relevant.

History: Cr. Register, March, 1985, No. 351, eff. 4-1-85.

APPENDIX C

TECHNICAL BULLETIN NO. 88:

GUIDELINES FOR THE APPLICATION OF WASTEWATER SLUDGE TO AGRICULTURAL LAND IN WISCONSIN

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GUIDELINES FOR THE APPLICATION OF WASTEWATER SLUDGE TO AGRICULTURAL LAND IN WISCONSIN

Technical Bulletin No. 88
DEPARTMENT OF NATURAL RESOURCES
Madison, Wisconsin

1975

PREFACE

This publication gives guidelines for applying processed (i.e., not raw) sewage sludge to agricultural and forest lands. It has been prepared to assist Wisconsin Department of Natural Resources personnel in the granting of discharge permits (Chapter 147, 1973 Assembly Bill 128). Section 147.02, Water Pollutant Discharge Elimination; Permits, Terms and Conditions, states that "the disposal of sludge from a treatment work by any person shall be unlawful unless such disposal is done under a permit issued by the department". Section 147.26, Design of Publicly Owned Treatment Facilities, states that "the department shall encourage the design of publicly owned treatment works which provide for: (a) The recycling of sewage pollutants by using them in agriculture, silviculture or aquaculture; (b) The ultimate disposal of sludge in a manner not resulting in environmental hazards".

Municipalities constructing wastewater sewage treatment plants under the state and federal cost-sharing grant programs must prepare a Facilities Plan. Sludge application on land must be considered as an alternative disposal method. This guideline can be used for screening the land application alternative, evaluating of environmental effects, assessing of other important non-monetary effects, and for developing a land application program in consultation with qualified specialists if this alternative is selected. The guideline addresses the properties of sludge and alternative handling methods, factors that determine environmentally-acceptable loading rates, current application technology and site selection, management and monitoring. It does not consider specifics of all possible site properties, handling options and management variables. It was prepared by the University of Wisconsin Soil Science Department and the Wisconsin Department of Natural Resources.

These guidelines are based on current knowledge and should be revised as new information becomes available. Factors affecting the limitations to sludge application rates from heavy metals are not well understood, and new technology for sludge application should become available in the near future.

GUIDELINES FOR THE APPLICATION OF WASTEWATER SLUDGE TO AGRICULTURAL LAND IN WISCONSIN

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Technical Bulletin No. 88
Department of Natural Resources
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I. INTRODUCTION

Disposal of wastewater sludge is the pivotal question in wastewater processing. Sludges contain the concentrated wastes of the community, and certain components of some sludges may be toxic and hazardous, depending on their concentration and the intended means of disposal. The hazardous components of sludges are the heavy metals [principally cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), copper (Cu), nickel (Ni), and mercury (Hg)], pathogenic bacteria and virus. Discharge of these components as well as the nutrients, nitrogen (N) and phosphorus (P), to surface and ground waters must be minimized to prevent degradation in water quality. The high salt content of sludges can inhibit plant growth if applied to soils at the wrong time.

The concept of "recycling" sludge nutrients to agricultural land is feasible and desirable. Sewage sludge is a low-analysis fertilizer of extremely variable composition. Transportation, handling, application and monitoring costs often put sludges at an economic disadvantage to the farmer compared to high-analysis commercial fertilizers. However, increasing fertilizer prices due to energy and supply shortages have put sludge in a more competitive position.

Aside from economics, the major problems involved in land application of sludge are public acceptance, possible surface and ground water contamination by overloading of nitrogen and phosphorus, pathogens, yield reductions due to overloading with heavy metals, and food chain contamination of toxic elements. Problems due to overloading of nitrogen can be controlled by using yearly loading rates approximating the nitrogen needs of the crop being grown. Phytotoxicity due to heavy metals is more difficult to predict, and affects the total loading of sludge (i.e., site lifetime). Disease transmission from land application of digested sludge does not appear to be a problem. However, toxic element contamination of the food chain, particularly by Cd, is not completely understood at present.

Overview of Sludge Production and Disposal

As wastewater treatment plants have been upgraded to improve effluent quality, the quantity of sludge produced has increased. This trend will doubtless continue. Farrell (1974) estimates an increase from 4.7 million dry tons in 1972 to 6.6 million tons in 1985 in the United States. For Wisconsin with a 3,115,000 sewered population and 80% (Konrad and Kleinert, 1974) on secondary treatment (.02 lb of solids/cap./day) and 20% on primary treatment (0.12 lb of solids/cap./day) an estimated total of 104,600 dry ton/year of sludge is generated currently. Assuming a 1985 sewered population of 3,500,000, all on secondary treatment, an estimated production of 127,750 dry tons/year can be predicted. Chemical treatment to remove phosphorus would increase the amount of sludge produced by 2 to 3 times that from conventional secondary systems (EPA, 1974). Assuming 3.5% N (50% available) and fertilizer application rates (150 lbs available N/acre), leads to an average application rate of 4.3 tons/acre. Thus, only about 24,000 acres (or less than 1% of the corn acreage) are needed to dispose of all of the sludge from Wisconsin municipalities. The point here is that land application of sludge has only a minimal impact on the fertilizer requirements of Wisconsin agriculture.

The current sludge treatment technology is covered in detail in a number of publications. Especially recommended are the Process Design Manual for Sewage Sludge Treatment and Disposal (EPA, 1974), Chapter 8 in Bolton and Klein (1971) and the Proceedings of the National Conference on Municipal Sludge Management held at Pittsburgh in June 1974. The conventional stabilization processes are anaerobic and aerobic digestion, while heavy chlorination, lime treatment, pasteurization (70°C), radiation and heat treatment (195°C) and various combinations of these methods have been used (Farrell, 1974). Digested sludges may be dewatered by various mechanical means such as the rotary vacuum filter, centrifuge, drying beds, or the filter press.

The main methods of sludge disposal in inland states at present are landfills, permanent lagoons, incineration and land application to (a) dispose of the material, (b) fertilize agricultural or recreational land, or (c) reclaim marginal land. Landfills specifically designed and operated for the disposal of sludges carrying high concentrations of hazardous materials can be used for sludge disposal. Proper incineration, while a satisfactory disposal method of volume reduction, suffers from increasingly higher operating costs, and the sophisticated technology involved. Promising future disposal schemes, at least for larger municipalities, include composting with carbonaceous solid wastes. Also co-incineration and co-pyrolysis of sludge with solid waste, which does not require supplemental fuel and yields some usable byproducts, is under development.

Sludge Properties

Sewage sludges vary so widely in chemical and physical composition that no truly average value for the content of solids, nutrients or metals can be given. This heterogeneity occurs from city to city, depending upon the treatment process used and major industries, and also from day to day in the same city. Thus one must recognize the limitations in dealing with a product of variable and largely uncontrollable quality.

Table 1 gives the ranges in various chemical constituents found in sludges from 35 Wisconsin municipalities. These data are from a recent Department of Natural Resources survey. Also, a survey by Kelling (1974) of the day-to-day variation in sludge composition of the Janesville Sewage Treatment Plant showed that, over a 2-week period, the solids content varied by as much as 100%, and the concentration of various elements varied from 10 to 100%.

To translate the results of Table 1 into more meaningful terms, one acre-

TABLE 1. *Range of concentration of various constituents in anaerobic liquid digested sludge from 35 Wisconsin municipalities. Metals data reported in Konrad and Kleinert (1974).*

Constituent	Range*
Total-N (moist)	3.4 - 9.5
Total-N (dried)	2.4 - 3.1
NH_4-N (moist)	0.8 - 4.1
NH_4-N (dried)	0.02 - 0.26
Organic C	25.7 - 38.5
P	2.7 - 6.1
K	1.2 - 1.9
Ca	4.2 - 18.0
Mg	0.8 - 1.2
Na	0.6 - 2.2
Al	0.36 - 1.2
Fe	0.8 - 7.8
Cd/Zn	0.15 - 33
Zn	490 - 12,200
Cu	140 - 10,000
Ni	15 - 1,700
Cd	5 - 400
Pb	40 - 4,600
Cr	50 - 32,000
Hg	0.6 - 31
B	150 - 750
Mn	180 - 1,130
Ba	530 - 1,340
Sr	52 - 7,810

*Range for the first 13 constituents is given in % of solids and in mg/kg for the last 11 constituents.

inch of sludge could add up to 550 lbs of N, 200 lbs of P (450 lbs of P_2O_5), 100 lbs of K (120 lbs of K_2O), 1,000 lbs of Ca, 100 lbs of Mg and Na, and as much as 300 lbs of Cr, 100 lbs of Cu and Zn, 50 lbs of Pb, 15 lbs of Ni, 2 lbs of Cd and 0.1 lb of Hg. Thus, it is obvious that problems from the high concentration of these elements may occur. The N load is the limiting factor on a short-term (yearly) basis, while accumulation of heavy metals may limit the amount of material applied over longer time periods.

While sufficient information is not available on the pathogenic agents in sludges, Ewing and Dick (1970) feel that the disease transmission hazard is not great, based mainly on the fact that no incidence of disease has been traced to sludge-disposal operations. However, since possible disease transmission is one of the greatest causes for public concern with waste handling operations, this subject must be carefully considered in drawing up guidelines.

The reviews by Ewing and Dick (1970) and Dean and Smith (1973) cite references indicating that fecal coliforms, *Salmonella*, *Pseudomonas* and *Endamoeba hystolytica* populations have high die-off rates in aerobic and anaerobic digesters. However, tubercle bacilli, some parasite ova, ascarids and hookworms appear to survive during digestion and even during drying of sludge. Lime (pH 11.5), pasteurization and direct steam injection will effectively destroy most pathogens, but these methods are expensive. Prolonged storage (two months or longer) appears to be an inexpensive and effective method of pathogen reduction.

II. FACTORS DETERMINING SLUDGE APPLICATION RATES TO AGRICULTURAL SOILS

There are a number of interrelated factors which affect the *annual* and *total* loading of sludges. *Annual rates*, assuming the recycling concept (i.e., use of the sludge as a fertilizer) will be influenced by mode of application, soil productivity and crops grown and level of site management.

Mode of Application

When liquid sludge is applied on the soil surface, clogging of the soil occurs, and drying and infiltration is slow. Thus, unless the sludge is incorporated, most of the sludge water will evaporate, rather than infiltrate the soil. On evaporation, considerable ammonium-N will be volatilized. The actual amount lost to the atmosphere will vary, but best estimates indicate that, on the average, about 50% of the sludge ammonium-N will be removed. This represents a loss of resources, and means that the actual N applied must be adjusted upward to compensate for ammonium volatilization.

If the sludge is incorporated immediately after application or applied by knife-plow-down equipment, volatilization losses are minimal.

Year-to-year variations in the weather will also affect application rates. Less sludge can be applied during rainy spells, and sludge should not be applied on frozen sloping land with snow cover.

Soil Productivity Potential and Crops Grown

Due to differences in climate and soil properties, there is considerable difference throughout the state in the maximum obtainable yields of crops such as corn. These differences must be taken into account when making recommendations for sludge disposal, just as they are taken into account in fertilizer recommendations. For example, maximum corn yields in the northern part of the state are limited by the much shorter frost-free growing season.

Crops use different amounts of nutrients. Corn and sorghum-sudan, for example, require more N than do such short-season crops as oats. Also, corn for silage removes more N than does corn grain. Legumes, such as alfalfa and soybeans, do not require any fertilizer N since they are capable of fixing their own supply from the N in the atmosphere. However, legumes will use available soil N when present in preference to fixation of atmospheric N.

Site Management

The level of management of the site will have considerable effect on nutrient recycling. For example, if an essential nutrient such as potassium (K) is in short supply, crop growth would be reduced and less N would be used by the crop. In some instances, use of a fall cover crop or double cropping will increase nutrient utilization. Site management plans should remain somewhat flexible to permit maximal nutrient utilization and economic returns.

To more adequately understand the factors involved in using sludge as a fertilizer, the "cycles" of N, P, and K are briefly reviewed.

Nitrogen*

The atmosphere contains about 78% nitrogen gas (N_2). However, most plants cannot use nitrogen as it exists in the atmosphere. For plants to use atmospheric nitrogen, it must be converted biologically or chemically.

Rhizobia and other bacteria which live in the roots of legumes take nitrogen from the air and fix it in a form which is usable by the plants. This mutually beneficial relationship between micro-organisms and plants is called symbiosis.

Nitrogen in Soils

Sources. Natural sources of nitrogen (other than from fertilizers) include organic matter, legumes, and precipitation.

Soils often contain 2,000 to 6,000 lbs/A of organic N, but almost all of this N is combined in stable organic matter (humus) which contains about 5% N and decomposes very slowly. Research shows that mineral soils in Wisconsin supply only about 25 to 75 lbs/A of available N annually. As a result, more nitrogen generally must be applied on nonlegume crops to achieve optimum yields.

Legumes inoculated with the proper strain of nodule-forming bacteria use atmospheric N by symbiotic fixation (Reaction 1, Fig. 1). If sufficient soil N is not available, legumes fix all the N they need and thus do not need N fertilizer. Many legumes will also supply substantial amounts of N to the next crop. An estimate of the nitrogen credit which should be given to various legume crops is given in Table 2.

In rural areas in Wisconsin precipitation adds about 10 lbs/A of available N (ammonium + nitrate nitrogen) annually. This is a small addition on a per-acre basis, but it is a significant contribution to the total N budget for the state. In fact, the total amount of N added to the state in precipitation exceeds the amount of N presently applied as fertilizer on croplands.

Processes. The following are microbiological processes that nitrogen undergoes in the soil:

Ammonification (or mineralization) is the conversion of organic N into ammonium by soil microbes (Reaction 2, Fig. 1). Plants can use ammonium N and it is not lost by leaching. Negatively charged particles of clay minerals and soil organic matter hold the positively charged ammonium ion (NH_4^+). This greatly restricts its movement by percolating water.

In the manufacture of chemical nitrogen fertilizer, atmospheric nitrogen is combined with hydrogen (H_2) to form ammonia (NH_3). Ammonia is sold for direct application, or it can be used to manufacture other forms of nitrogen fertilizer such as ammonium nitrate (NH_4NO_3) or urea (NH_2-CO-NH_2).

Nitrogen tends to be a rather elusive element because it exists in many different forms, and its availability to plants is affected by several physical, chemical and biological processes. These transformations, collectively called the nitrogen cycle, are illustrated in Fig. 1.

Nitrification is the transformation of NH_4-N to NO_3-N by soil bacteria (Reaction 3, Fig. 1). Nitrate is readily available to plants, but it is negatively charged and thus remains in solution in the soil. Therefore, it may be leached below the root zone as water percolates through the soil. Nitrification occurs rapidly in warm, well-aerated and properly limed soils (pH of 5.6-8.0). Under favorable conditions, the ammonium form of N is changed to the nitrate form in one to two weeks after application.

Immobilization is the process whereby crop residues rich in carbon, such as straw or corn stalks, are plowed under, and the available ammonium or nitrate is temporarily immobilized by the bacteria that decompose the residues (Reaction 5, Fig. 1). But soon after the crop residues begin

TABLE 2. *Suggested nitrogen credits for various legume crops.*

Legume Crop	Nitrogen Credit (lbs/A)
Sod alfalfa	
60-100% stand	80-100
20- 60% stand	40- 60
0- 20% stand	0- 20
Red Clover	40- 60
Green-Manure*	
Alfalfa	40- 60
Sweet clover	60- 80
Cash Crops**	
Peas, snapbeans, lima beans, soybeans	10- 20

*Based on plowing under the green manure crop after the growing season of the seedling year.

**Based on plowing under the vines or other plant residues.

TABLE 3. *Percentages of nitrogen considered deficient, low, sufficient, and high for major Wisconsin field crops.*

Crop	Plant Part Sampled	Time of Sampling	Interpretation (in % N)			
			Deficient	Low	Sufficient	High
Corn	ear leaf	silking	<1.75	1.75-2.75	2.76-3.75	>3.75
Oats, wheat, barley	top leaves	boot stage	<1.50	1.50-2.00	2.01-3.00	>3.00
Alfalfa*	top 6 inches	early bud	<1.25	1.25-2.50	2.51-3.70	>3.70

*First Crop

*Adapted from U.W. Extension Fact Sheet A2519, Soil and Applied Nitrogen, by L.M. Walsh.

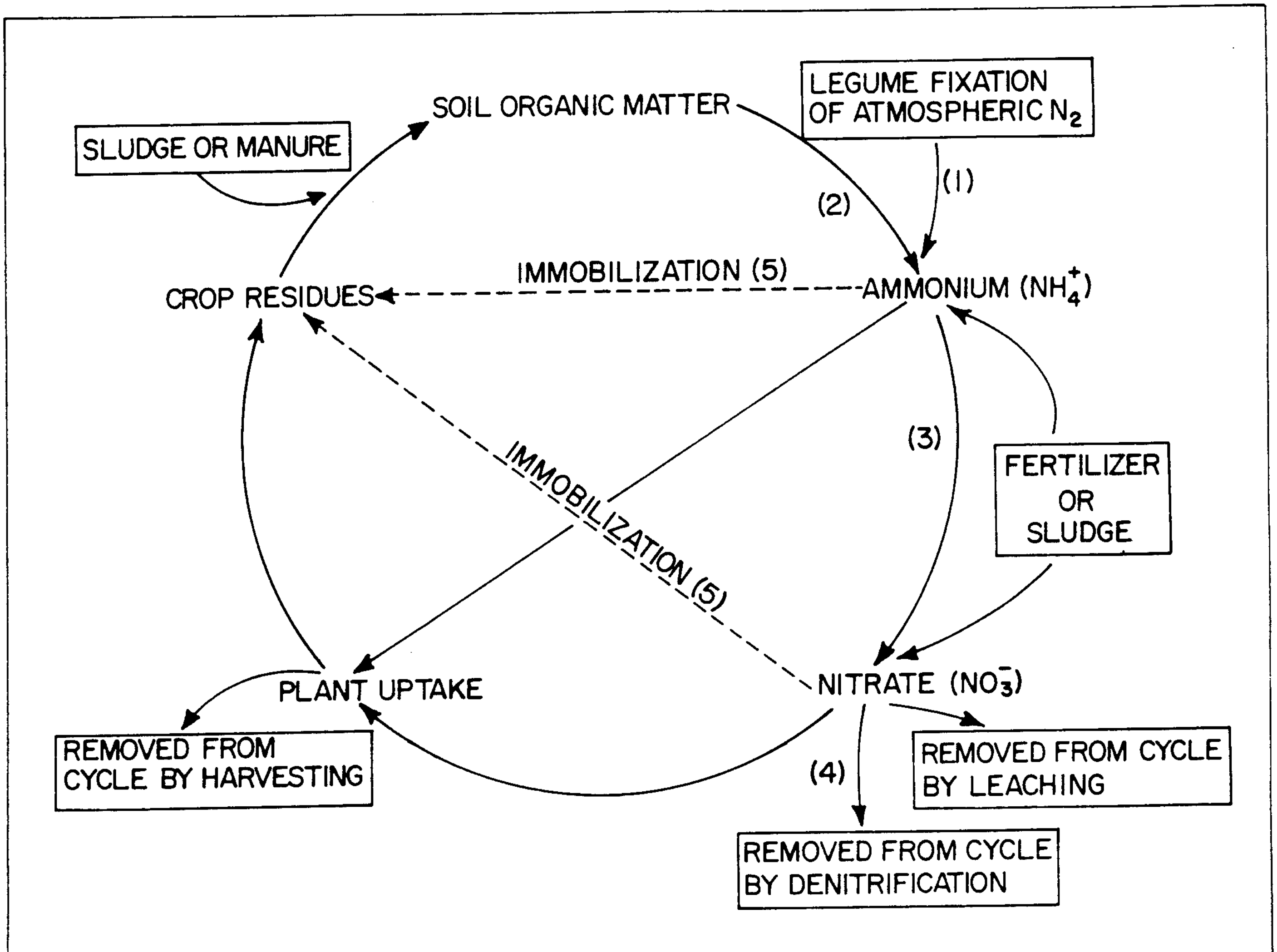

FIGURE 1. *The nitrogen cycle.*

to decompose, N immobilized as microbial protein is released again in an available form. Under ideal weather conditions, release of immobilized N begins about one month after plowing or discing of the organic matter.

Losses. Nitrogen is lost from the soil profile by several means. Leaching of nitrate can be a serious problem, especially on sandy soils. Since sandy soils retain only about one inch of water per foot of soil, relatively small amounts of rain or irrigation water readily move nitrate below the root zone. Well-drained silt and clay soils retain about three inches of water per foot of soil, so much less leaching occurs on these soils, except when rainfall is abnormally high. Ammonium-N is held on soil particles and is essentially nonleachable. Nitrate is not held by soil particles and can be leached below the root zone. But this does not mean that ammonium is more effective than nitrate. As pointed out previously, soil bacteria rapidly convert ammonium to nitrate under optimum soil conditions. As a result, very little difference in N loss occurs between ammonium and nitrate forms of N.

A second means of nitrogen loss is volatilization. When sludge is surface applied and not worked into the soil, some nitrogen can be lost as ammonia gas. Injection or immediate incorporation of liquid sludge eliminates most of the volatilization losses.

Nitrogen is also lost by **denitrification.** In poorly aerated, water-logged soils, soil bacteria change available nitrate into unavailable atmospheric N (Reaction 4, Fig. 1). For denitrification to occur, decomposable organic matter must be present as a source of energy. Because of this energy requirement, denitrification does not take place deep in the sub-soil or in groundwater. Denitrification takes place very rapidly. If water stands on the soil for only two or three days during the growing season, most of the nitrate will be lost by denitrification. Yellowing of corn and other crops grown on poorly aerated soils is due in large part to a N deficiency.

Environmental Hazards

If nitrate-N is applied in amounts greater than can be removed by plant uptake, the excess nitrates can potentially contaminate groundwater or surface waters by leaching or runoff. Through groundwater contamination, excessive nitrate in drinking water may cause human and animal health problems. The US EPA and World Health Organization drinking water standard is 10 mg/liter of nitrate-N. Surface water contamination with excess nitrate and other nitrogen compounds may hasten deterioration of streams and lakes by promoting excessive growth of algae and weeds. The same hazards exist when N fertilizer or farm animal wastes are used on croplands. However, if the recommendation of annual sludge application rates, which is usually limited by available N, is closely observed, excessive accumulation of nitrate will not be a problem.

Diagnostic Techniques

Deficiency Symptoms. Lack of N first appears as a light green coloring of the plant. As the deficiency becomes more severe, leaves turn yellow and may "fire". The deficiency appears on the lower leaves first and gradually progresses up the plant. On corn the yellowing first starts at the midrib of the leaf with the edge of the leaf remaining green. Corn, small grain and forage grasses have a relatively high N requirement and show deficiency symptoms whenever N is in short supply.

Plant Analysis. Analysis of the plant tissue gives a good indication of whether the plant contains sufficient N. The amount of total N (crude protein) in a plant decreases as the plant grows. Therefore, it is important to specify the stage of growth when sampling a crop for N analysis. An interpretation of the results of N analyses for the major agronomic crops grown in Wisconsin is presented in Table 3.

Phosphorus*

Soils generally contain 1,000-2,000 lbs/A of total P, but most of this P is in an unavailable or "fixed" form and cannot be used by plants. Furthermore, soluble P is quickly "fixed" when added to the soil. Because of the relative low quantity of total P in the soil and the fixation of native and applied P, continued use of P fertilizer is required on most Wisconsin soils.

Phosphorus in Soils

Phosphorus in soils is classified into two main categories: organic and inorganic. The organic part is found in humus and other organic materials. The inorganic portion occurs in numerous combinations with iron, aluminum, and other elements, most of which are insoluble in water.

Acid soils fix more P than neutral soils. Therefore, liming acid soils tends to increase the availability of both soil and fertilizer P.

Phosphorus in Organic Matter. The relative amount of P in the organic and inorganic forms varies considerably. In Wisconsin, organic P accounts for 30-50% of the total P in most mineral soils.

Organic forms of P can be mineralized to inorganic forms. This occurs during the decomposition of organic matter. As with the mineralization of organic N, organic P is released more rapidly in warm, well-aerated soils. This explains why crops grown in cold wet soils often respond to row-applied P in Wisconsin, even though the soil may be well supplied with available soil P or broadcast P fertilizer.

Environmental Hazards

Since soil particles contain a very high degree of retention capacity for phosphate, ground water is usually protected from P contamination. Although the ultimate capacity for P fixation by soil is not unlimited, it is unlikely that sludge application will exceed this capacity. Some evidence exists that organic forms of P are more mobile in soils, but to date no documented evidence for extensive leaching of P below feedlots or sludge application sites has been reported. However, surface water contamination with phosphates is of more concern. When excessive amounts of P are added to a lake or stream, luxurious growth of weeds and algae often results. Of the plant nutrients, P is the most closely related to over-production of weeds and algae. Therefore, surface runoff and erosion of sludge-applied lands into surface waters should be minimized.

Phosphorus Fixation. Phosphorus forms a negatively charged phosphate ion ($H_2PO_4^-$). Since the soil particles are also negatively charged, it might appear that phosphate could leach away like nitrate. But this does not occur because phosphate reacts rapidly with the soil solids. It is then "fixed" in an unavailable form.

One of the unique characteristics of P is its immobility in soil. Practically all soluble P in sludges or fertilizer is converted to water-insoluble P within a few hours after application. Hence, P does not leach, even on sandy soils. Studies on highly fertilized, intensively farmed land indicate that the annual loss of P in drainage water seldom exceeds 0.1 lb/A. Furthermore, 98-99% of the fertilizer phosphorus is usually found in the plow layer of the soil, indicating that very little phosphorus moves through the subsoil.

Diagnostic Techniques

Deficiency Symptoms. The leaves of P-deficient plants most often appear dark bluish green, frequently combined with tints of purple or bronze. On corn, purpling occurs around the margins of the leaf and the plant is short and dark green. Reddening of corn leaves and stalks in the fall is not an indication of P deficiency. Phosphorus-deficient alfalfa appears short and dark green, but purpling does not occur.

Soil Analysis. Many methods exist for measuring available P in soils. A test developed at Illinois—the Bray P_1—is used in Wisconsin and throughout the midwest. The interpretation of the Bray P_1 test for Wisconsin soils is shown in Table 4. Recommendations for P fertilizer vary with crop species, yield goal, soil type and level of management. If soils tests are below optimum levels, both corrective and maintenance fertilizer is required.

Plant Analysis. Analysis of plant tissue gives a good indication of the P nutrition of the plant. Since phosphorus levels in the plant change with age, it is best to indicate the stage of maturity at sampling. An interpretation of phosphorus levels in the leaf tissue for the major Wisconsin field crops is given in Table 5.

Estimation of P Sorption Capacity

When a sample of soil is shaken with a phosphate solution, much of the P is sorbed on the soil. If the concentration of phosphate is varied keeping the weight of soil constant, and the residual phosphate in solution determined, the data can be treated with an equation known as the Langmuir adsorption isotherm (Ellis, 1973). This equation gives a number of soil-related parameters, including a maximum sorption capacity. Ellis (1973) has proposed using this value to rate soils in terms of the amount of phosphorus they will adsorb in the top 3 feet. This rating was used by Schneider and Erickson (1972) to classify Michigan soils in terms of suitability for use in municipal waste water irrigation. The approach is still being evaluated at Michigan, and is not recommended for site evaluation at this time. However, further research may show its utility, and if P sorption capacity tests are contemplated, consultation with U.W. Soils Dept. personnel is advised.

*Adapted from U.W. Extension Fact Sheet A2520, Soil and Applied Phosphorus, by L.M. Walsh.

Potassium*

Soils commonly contain over 20,000 lbs/A of total K. However, nearly all of this K is a structural component of mica, feldspar and other soil minerals and is not available to the plant. Plants can use only the exchangeable K on the surface of the soil particles. This often amounts to less than 200 lbs/A of K.

Crops such as corn silage and alfalfa remove large quantities of K. Most Wisconsin soils need rather large quantities of K fertilizer because of removal by crops and because Wisconsin soils were not initially well supplied with exchangeable K.

Potassium in Soils

Forms of Soil K. Three forms of soil K are often described; unavailable, slowly available or "fixed", and readily available or exchangeable. Unavailable soil K is contained in micas, feldspars, and clay minerals. Plants cannot use K in these crystalline, insoluble forms. Over long periods these minerals weather or decompose and their K is released as the available K^+ ion. This process is far too slow to take care of the K needs of field crops. However, trees and long-term perennials obtain a substantial portion of the K they require from the weathering of minerals containing K. Slowly available K is trapped between the layers or "plates" of certain kinds of clay particles. This is sometimes called "fixed" K. Plants cannot use much of the slowly available K during a single growing season. However, the soil's ability to supply K over a longer period of time is related closely to its supply of fixed K. For instance, compared to other soils in Wisconsin, the sandy and silty soils in the central and northcentral regions of the state have lower soil tests for available K because they have a very low supply of fixed K.

Readily available K is held on the surface of clay and other soil particles. Plants easily absorb K in this form. Soil tests for available K are designed to extract only the readily available form. Most soil tests do not remove the unavailable and slowly available forms of K. Since sewage sludge typically is low in K relative to its N and P contents, K fertilizer often will need to be added. The most common K fertilizer for use on field crops is KCl (muriate of potash). This is the least expensive source of K and it is just as effective as the other sources. For that reason it is usually recommended except when the crop also needs sulfur (S) or magnesium (Mg). Also, some specialty crops require the use of the sulfate form of K (K_2SO_4) to maintain crop quality. For example, tobacco will not burn properly when chloride (Cl) is added to the soil; so it should be fertilized with sulfate forms of K.

TABLE 4. *Soil test level for phosphorous.*

Crop Type	Concentration of Available P (in lbs/A)		
	Minimum	Optimum	Excessive
Field crops including sweet corn and peas	30-50	50-100	over 125
Vegetable crops and irrigated field crops	50	75-150	over 200

TABLE 5. *Percentages of phosphorus considered deficient, low, sufficient, and high for major Wisconsin field crops.*

Crop	Plant Part Sampled	Time of Sampling	Interpretation (in % P)			
			Deficient	Low	Sufficient	High
Corn	ear leaf	silking	<.16	.16-.24	.25-.50	>.50
Alfalfa	top 6 inches	early bud	<.20	.20-.25	.26-.70	>.70
Oats	top leaves	boot stage	<.15	.15-.20	.21-.50	>.50

TABLE 6. *Soil test level for potassium.*

Crop Type	Concentration of Available K (in lbs/A)		
	Minimum	Optimum	Excessive
Field crops including sweet corn and peas	200	200-300	over 400
Vegetable crops and irrigated field crops	250	250-350	over 500

TABLE 7. *Percentages of potassium considered deficient, low, sufficient and high for major Wisconsin field crops.*

Crop	Plant Part Sampled	Time of Sampling	Interpretation (in % K)			
			Deficient	Low	Sufficient	High
Corn	ear leaf	silking	<1.25	1.25-1.74	1.75-2.75	>2.75
Alfalfa	top 6 inches	early bud	<1.80	1.80-2.40	2.41-3.80	>3.81
Oats	top leaves	boot stage	<1.25	1.25-1.59	1.60-2.50	>2.50

Environmental Hazards

Potassium is not an environmental hazard, as it possesses no harm to higher life and is not related to eutrophication in lakes or streams. Furthermore, K is readily and tightly held by soil particles, and there is little potential of K leaching into ground or surface waters.

Diagnostic Techniques

Deficiency Symptoms. On corn, soybeans and other field crops K deficiency appears as a yellowing or scorching on the margins of the leaves. The area affected increases as the deficiency becomes more severe. Since K is a very mobile element within the plant, the deficiency appears on the older leaves first. On alfalfa the deficiency appears as whitish-grey spots along the outer margin of the recently matured and older leaflets.

*Adapted from U.W. Extension Fact Sheet A2521, Soil and Applied Potassium, by L.M. Walsh.

Soil Analysis. Available K is estimated by measuring the exchangeable K; that is, the potassium on the surface of the soil particles. Interpretation of the exchangeable or available K test for Wisconsin soils is listed in Table 6. Recommendations for K fertilizer vary with crop specie, yield goal, soil type and level of management. If soil tests are below optimum levels, both corrective and maintenance fertilizer is required; for optimum soil tests only maintenance fertilizer is required; and for excessively high tests part or possibly all the maintenance fertilizer can be eliminated.

Plant Analysis. Critical concentrations of K for the crops of major economic importance are fairly well known. Like N, the amount of K in the plant decreases as it matures. Therefore, to interpret the results of K analysis, it is important to know the stage of growth. Also, the K content usually decreases from top to bottom of the plant, so the portion of the plant sampled must be known as well. Interpretation of K levels in the leaf tissue for the major Wisconsin field crops is given in Table 7.

Calculation of Annual Sludge Application Rates Based On Nitrogen

Corn Yield Potentials and Nitrogen Needs

Soil surveys give yield potentials of all soils mapped in the county. These surveys should be consulted when available. If such information is not available, the following tables should be consulted.

Table 8 gives the expected corn yields under very high levels of management, and Table 9 gives the yield potential for each county for sands and loamy soils (coarse-textured soils) and for finer textured soils (sandy loams, silt loams and clay loams). The corn yield potential for each soil series is given in Appendix A.

Table 10 gives the N fertilizer recommendations taking into account N released from the soil organic matter over the growing season.

Nitrogen Availability from Sewage Sludge

When sewage sludge is added to soil, its organic matter slowly decomposes releasing available N. Experimental evidence suggests that on silt loam and clay soils about 15 to 20% of the sludge N is mineralized the first year, whereas on sands and sandy loams, which are better aerated, the mineralization rate will be greater. After initial sludge application, about 6, 4, and 2% of the remaining N is released for the subsequent three years (Table 11). This must be taken into account in repeated sludge applications. Thus, sludge application rates are based on crop needs, the quantity of NH_4-N in the sludge, the N released during sludge decomposition and the N from the soil.

Nutrient Utilization by Various Crops

Table 12 gives the N, P, and K uptake by various crops. These values can be used to estimate N needs by other

TABLE 8. *Relative yield potential of the soil and expected corn yield.*

Yield Potential Code	Relative Yield Potential of the Soil*	Expected Yield (bu/A)
1	Very high	120-140
2	High	100-120
3	Medium	80-100
4	Low	60- 80

*With exceptionally high management, 20 bu/A more can be expected.

TABLE 9. *Yield potential codes by county.*

County	Yield Potential Code*: Sandy Loams, Silts and Clay Loams**	Yield Potential Code*: Sands and Loams	County	Yield Potential Code*: Sandy Loams, Silts and Clay Loams**	Yield Potential Code*: Sands and Loams
Adams	2	3	Marathon	3	4
Ashland	3	4	Marinette	3	4
Barron	3	4	Marquette	1	3
Bayfield	3	4	Menomonie	3	4
Brown	2	3	Milwaukee	2	3
Buffalo	2	3	Monroe	1	3
Burnett	3	4	Oconto	3	4
Calumet	2	3	Oneida	3	4
Chippewa	2	3	Outagamie	2	3
Clark	2	3	Ozaukee	2	3
Columbia	1	3	Pepin	2	3
Crawford	1	3	Pierce	2	3
Dane	1	3	Polk	2	3
Dodge	1	3	Portage	2	3
Door	3	4	Price	3	4
Douglas	3	4	Racine	1	3
Dunn	2	3	Richland	1	3
Eau Claire	2	3	Rock	1	3
Florence	3	4	Rusk	3	4
Fond du Lac	1	3	St. Croix	2	3
Forest	3	4	Sauk	1	3
Grant	1	3	Sawyer	3	4
Green	1	3	Shawano	3	4
Green Lake	1	3	Sheboygan	2	3
Iowa	1	3	Taylor	3	4
Iron	3	4	Trempealeau	2	3
Jackson	2	3	Vernon	1	3
Jefferson	1	3	Vilas	3	4
Juneau	2	3	Walworth	1	3
Kenosha	1	3	Washburn	3	4
Kewaunee	2	3	Washington	1	3
LaCrosse	1	3	Waukesha	1	3
Lafayette	1	3	Waupaca	2	3
Langlade	3	4	Waushara	2	3
Lincoln	3	4	Winnebago	2	3
Manitowoc	2	3	Wood	2	3

*The relative yield potential of the soil for corn is coded as follows: 1. Very high; 2. High; 3. Medium; 4. Low.

**All irrigated sands are included in this group.

TABLE 10. *Nitrogen needed by corn (in lbs/A of N needed).**

Yield Potential	Organic matter content 0-20 Tons/A	21-35 Tons/A	36-50 Tons/A	50 Tons/A
1. Very high**	160	140	120	100
2. High	140	120	100	80
3. Medium	120	100	80	60
4. Low	100	80	60	60

*Of nonsludged soil, no data are available to evaluate nitrogen availability of soil organic matter from sludge-treated soil.

**With exceptionally high management, 20 lbs additional N is needed.

TABLE 11. *Release of available nitrogen per ton of solids during sludge decomposition.*

Years after Sludge Application	Mineralization Rate, %	Organic N Content of Sludge* 2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%
First	15.0	6.0**	7.5	9.0	10.5	12.0	13.5	15.0
Second	6.0	2.4	3.0	3.6	4.2	4.8	5.4	6.0
Third	4.0	1.6	2.0	2.4	2.8	3.2	3.6	4.0
Fourth	2.0	0.8	1.0	1.2	1.4	1.6	1.8	2.0

*Expressed in lbs N released/ton sludge added.

**2000 lb/ton x 0.02 x 0.15 where 0.02 is the percent organic N and 0.15 is the mineralization rate/100.

TABLE 12. *Nitrogen, phosphorus, and potassium uptake by various crops.*

Crop	Yield per acre*	Uptake (in lbs/A)*** N	P_2O_5	K_2O
Corn	120 bu	150	65	170
	140 bu	185	80	185
Corn silage	32 tons	200	80	240
Soybeans	50 bu	257**	50	120
	60 bu	336**	65	145
Grain sorghum	8000 lbs	250	90	200
Wheat	60 bu	125	50	110
	80 bu	186	55	160
Oats	100 bu	150	55	150
Barley	100 bu	150	55	150
Alfalfa	8 tons	450**	80	480
Orchard grass	6 tons	300	100	375
Brome grass	5 tons	166	65	255
Tall fescue	3.5 tons	135	65	185
Bluegrass	3 tons	200	55	180

*Values reported are for the total above-ground portion of the plants. Where only grain is removed from the field, a significant proportion of the nutrients are left in the residues. However, since most of these nutrients are temporarily tied up in the residues, they are not readily available for crop use. Therefore, for the purpose of estimating nutrient requirements for any particular crop year, complete crop removal can be assumed.

**Legumes get most of their N from the air so additional N sources are not normally needed.

***P_2O_5 x 0.437=P and K_2O x 0.83=K.

TABLE 13. *Corrective phosphorus and potassium recommendations for corn.**

Phosphorus Soil Test (lb/A)	Potassium soil test 0-100 lb/A	100-140 lb/A	140-180 lb/A	180-240 lb/A	>240 lb/A
0-15					
P_2O_5	90	90	90	90	90
K_2O	240	180	120	60	0
16-30					
P_2O_5	60	60	60	60	60
K_2O	240	180	120	60	0
31-45					
P_2O_5	30	30	30	30	30
K_2O	240	180	120	60	0
>45					
P_2O_5	0	0	0	0	0
K_2O	240	180	120	60	0

*Applied once during corn-oats rotation. Expressed in lbs/A recommended.

TABLE 14. *Maintenance phosphorus and potassium recommendations for alfalfa.**

Phosphorus Soil Test (lb/A)	Potassium soil test 0-240 lb/A	240-360 lb/A	>360 lb/A
0-40			
P_2O_5	50	50	50
K_2O	200	150	0
>40			
P_2O_5	0	0	0
K_2O	200	150	0

*Expressed in lbs/A recommended.

crops. However, in Wisconsin relative yield values have not been developed for crops other than corn. The P needs of all crops are similar, but the K needs vary considerably.

Tables 13 and 14 give the corrective applications of P and K needed for corn and alfalfa depending on soil test results. From these tables, one can calculate supplemental fertilizer needs in a sludge application program.

Since sewage sludge contains considerable P relative to the nitrogen needs of crops, sludge application based on the N requirements of the crop will invariably over-fertilize with respect to P. However, there is no information at present on the availability of the P in sludge from various treatment processes. Preliminary data indicate that the P in anaerobically digested sludges which have not received chemical treatment is equivalent to fertilizer P.

Calculations

The sludge application rate based upon crop nitrogen requirements can be calculated as outlined in Figure 2.

WITH SOIL TEST RECOMMENDATION

(1) Obtain nitrogen recommendation in lb/A = [A] from soil test results.

(2) Calculate the available N in sludge using the following formulas:

$$\% \text{ NH}_4\text{-N in sludge} \times \frac{2000 \text{ lb/ton}}{100 \text{ (conversion from \%)}}$$

$= \% \text{ NH}_4\text{-N} \times 20 =$ [B] lb NH_4-N/ton sludge

If surface applied and not incorporated immediately, reduce this value by one-half.

$$\% \text{ organic N} \times \frac{2000 \text{ lb/ton}}{100 \text{ (from \%)}} \times 0.15 \text{ (mineralization rate, 15\%)}$$

= % org. N x 3 = [C] lb org. N/ton

(3) Residual sludge N in soil = [D] lb N/A

If soil has received sludge in the past three years, calculate residual N from Table 11.

(4) Sludge application rate, tons/A

$$= \frac{\text{Nitrogen recommendation, lb/A} - \text{Residual N, lb/A}}{\text{available N/ton sludge}}$$

$$= \frac{[A] - [D]}{[B] + [C]} \text{ tons/A}$$

Example Calculation

Corn; Green County; yield potential, very high

Soil test results	Fertilizer Recommendations
Texture: silt loam	Corrective and Maintenance
Organic matter: 15 tons/A	N; 160 lb/A
Available P: 20 lb/A	P_2O_5; 100 lb/A
Available K: 110 lb/A	K_2O; 220 lb/A

Sludge Analyses

NH_4-N; 1.5% Organic N; 2.5% P; 2.0% K; 0.2% Surface application, 3rd year; 5 tons/A applied in year 1 and 2.

(1) Fertilizer N recommended = 160 lb/A = [A]

(2) Available N in sludge;
1.5 (% NH_4-N) x 20 x 0.5 (for surface application) = 15 lb/ton = [B]
2.5 (% organic N) x 3 = 7.5 lb/ton = [C]

(3) Residual N, from Table 11 for 2.5% organic N
Sludge added 1 year previous 5 tons/A x 3 = 15.0 lb/A
Sludge added 2 years previous 5 tons/A x 2.0 = 10 lb/A
Total residual N = 15 + 10 = 25 lb/A = [D]

(4) Sludge application rate $= \frac{[A] - [D]}{[B] + [C]} = \frac{160 - 25}{15 + 7.5} = \underline{6.0 \text{ tons/A}}$

(5) P added = 6.0 tons/A x 0.02 (% P) x 2000 lb/ton
= 240 lb P/A = 550 lb P_2O_5/A
No P_2O_5 needed.

(6) K added = 6.0 tons/A x 0.002 (% K) x 2000 lb/ton
= 24 lb K/A = 30 lb K_2O/A
K needed = 220 lb/A − 30 lb/A = 190 lb K_2O/A as fertilizer

WITHOUT SOIL TEST RECOMMENDATION

(1) Obtain N requirement from Tables 10 and 12 = [A] lb/A

(2) Calculate available N in sludge as in (a) above, [B] and [C] lb/A

(3) Residual sludge N in soil = [D] lb/A

If soil has received sludge in past three years, calculate residual N from Table 11.

(4) Sludge application rate, tons/A

$$= \frac{\text{crop N requirement} - \text{residual N}}{\text{available N in sludge}} = \frac{[A] - [D]}{[B] + [C]} \text{ tons/A}$$

Example Calculation

From Table 10, N needed for corn = 160 lb/A = [A]. The remainder of the calculations are as shown previously.

FIGURE 2. *Calculation of sludge application rate based on nitrogen loading.*

Heavy Metal Factors Affecting Total Sludge Loading

Total sludge loading may be limited by crop damage due to phytotoxic metals (Zn, Ni and Cu) and to Cd uptake by edible portions of the crop. Zinc and Cu are also required by plants in small amounts. Insufficient information is presently available to provide firm estimates of the amounts of these metals which may be added. The recommendations presented are based on the best information currently available and are conservative.

Toxicity of these elements is presented in Table 15, while Table 16 summarizes the main sources of these elements to the environment.

Retention Mechanisms in Soil

The main factors governing entry of an element into the above-ground portions of plants (excluding aerial contamination) are its availability in the soil, uptake by the roots and translocation.

The retention mechanisms in soils for these elements are numerous, complex, interrelated and predictably, poorly understood. Hodgson (1963) has grouped these reactions into: (1) ion exchange, (2) adsorption and precipitation, and (3) complexation. Figure 3 outlines the mechanisms that may operate to affect plant availability of metals. Several reviews of sorption mechanisms are available (Hodgson, 1963; Jenne, 1968; Ellis and Knezek, 1972; Ellis, 1973).

Cation exchange involves interaction of electrostatic bonding forces, and by definition are the ions that can be readily displaced from the soil by a neutral salt solution without decomposition of the solid matrix.

Soil cation exchange capacity (CEC) is usually estimated by saturating the soil exchange sites with a cation (such as Ca^{++} or NH_4^+), and displacing this cation by leaching with a salt solution such as KCl. Then the amount of cation displaced is measured, and CEC calculated. It is expressed as milligram equivalents (meq) per 100 g of soil. Although soil solids can possess both negative and positive charges, the net negative charge predominates in most temperate zone soils unless they are extremely acidic. The general concensus is that, for the elements in Table 15, nonspecific sorption reactions do not play an important role in their mobility in soils. This is based on the fact that only a small proportion are exchangeable with neutral salts, and that sorption studies with intact soils and with soil components indicate that sorption sites with higher activation energies are involved.

In arable soils, and at background levels, sorption and complexation reactions would appear to control the mobility of these elements. When they are added to soils, the relative dominance of precipitation of discrete compounds over other sorption mechan-

TABLE 15. *Potential toxicity of heavy metals.*

	Essentiality		Toxicity	
Element	Plants	Animals	Plants*	Animals
Cadmium	No	No	Moderate	High**
Chromium	No	No	Low	Low
Copper	Yes	Yes	High	Moderate
Lead	No	No	Low	High**
Mercury	No	No	Low	High**
Nickel	No	Yes	High	Moderate
Zinc	Yes	Yes	Moderate	Low

*When metal is applied to the soil.
**Cumulative effects.

TABLE 16. *Sources of metals to the environment.*

	Source	
Element	General	Specific
Cd	Agricultural	Impure phosphate fertilizers
	Industrial	Electroplating, pigments, chemicals, alloys, automobile radiators and batteries
Cr	Industrial	Refractory bricks, plating of metals, dying and tanning, corrosion inhibitors
Cu	Electrical	Wire, apparatus
	Plumbing	Copper tubing, sewage pipes
	Industrial	Boilers, steampipes, automobile radiators, brass
	Agricultural	Fungicides, fertilizers
Pb	Plumbing	Caulking compounds, solders
	Industrial	Pigments, production of storage batteries, gasoline additives, anti-corrosive agents in exterior paints, ammunition
Hg	Electrical	Apparatus
	Industrial	Electrolytic production of chlorine and caustic soda, measuring and control instruments, pharmaceuticals, catalysts, lamps (neon, fluorescent and mercury-arc), switches, batteries, rectifiers, oscillators, paper and pulp industries
	Household	Paints, floor-waxes, furniture polishes, fabric softeners, antiseptics
	Agricultural	Fungicides
Ni	Industrial	Electroplating, stainless and heat-resisting steels, nickel alloys, pigments in paints and lacquers
Zn	Agricultural	Pesticides, superphosphates
	Household	Pipes, utensils, glues, cosmetic and pharmaceutical powders and ointments, fabrics, porcelain products, oil colors, antiseptics
	Industrial	Corrosion-preventive coating, alloys of brass and bronze, building, transportation and appliance industries
	Plumbing	Galvanized sewage pipes

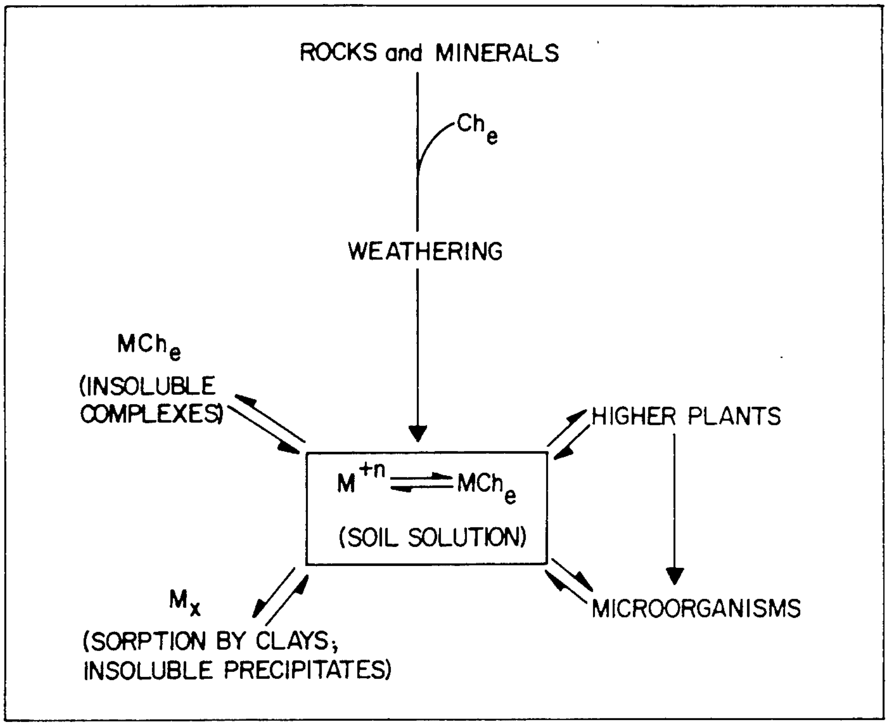

FIGURE 3. *Pathways for metal reactions in soils; M=metal, Ch_e=complex or chelate, x=clay (Stevenson and Ardakani, 1972).*

isms is a function of the concentration added as well as pH (Lindsay, 1972). Lindsay (1972) points out the difficulties of applying solubility product data to Zn and Cu availability in soils.

There is considerable evidence that sorption of metals in soils is predominantly by chelation and by hydrous metal oxides, particularly Fe, Mn, and Al. These oxides, which occur in variable forms ranging from discrete minerals to amorphous coatings, have high surface areas and are quite reactive. The Fe and Mn oxides are quite labile, since their formation and dissolution is dependent on pH and oxidizing-reducing conditions in soils. Jenne (1968) has postulated that the continual formation-dissolution of Fe and Mn hydrous oxides can explain many of the observations on heavy metal mobility in soils as related to flooding, organic matter content and pH.

In a general sense, heavy metal availability decreases as pH increases, and is minimal above pH 6.5. It has also been observed that immobilization of heavy metals in soils will continue slowly for months or years. This is referred to as "reversion" and is often attributed to solid state diffusion into crystalline materials, including clays and may be extremely important in diminishing the phytotoxic effects of over-application of metals.

Stevenson and Ardakani (1972) discussed the possibilities and mechanisms of organic-metallo complexes in soils. Figure 3 outlines these reactions. Deductive reasoning for the importance of these reactions involves (1) biochemical compounds having chelating characteristics are continuously produced (but also degraded) in soils; (2) humic and fulvic acids (the heterogeneous mixture of molecules forming the organic matter of soils) and extracts of plants exhibit strong complexation tendencies; and (3) heavy metal sorption is often related to the organic matter content of soils. Retention of Cu and Ni seems to be closely related to complex formation; conversely, soluble organic complexes can increase heavy metal mobility in soils (Stevenson and Ardakani, 1972). Jenne (1968) noted that metal sorption in soils is related closely to the chemistry of the hydrous metal oxides.

Environmental Hazards

(a) **Phytotoxicity.** The conclusion that phytotoxicity from land application of sludges will result mainly from Zn, Cu, and Ni has resulted in attempts to provide some common index of toxicity related to the amounts of these metals applied. This was first proposed by Chumbley (1971) as the "Zn equivalents" based on observations that Cu is twice as toxic and Ni eight times as toxic as Zn. Chaney (1973) elaborated on the concept, and proposed that soil sorption properties be accounted for by limiting the total "Zn equivalents" applied to 5% of the CEC (cation exchange capacity) of the soil. This approach is essentially being proposed by the U.S. EPA, although the limit has been raised to 10% of the CEC and Ni toxicity relative to Zn lowered to four. Chaney (1973) recommended overcoming the Cd problem by prohibiting land application of sludges with a Cd content greater than 1% of the Zn content.

None of these approaches are based on conclusive experimental evidence, since the data are not yet available. A number of complications which would result from a simplistic approach are readily apparent. For one, metals may not be equally available from sludges of different sources (Cunningham et al., 1975). For another, marked interactions between Cu, Zn, and Ni, and between these metals and other soil constituents (clay, organic matter, phosphate) will likely occur to affect their availability in different soils with similar CEC's. Also, secondary effects on the availability of other metals, principally Fe, might be expected.

Sorption of metals by soil colloids has commonly been observed to occur in amounts in excess of their cation exchange capacities (Ellis and Knezek, 1972). The bondings are probably at specific adsorption sites through covalent bonding to certain functional groups on the clay surfaces and to soil organic molecules. This bonding is often sufficiently stable to compete successfully with precipitation mechanisms, rendering solubility product considerations of little value.

Some specific results of interest include those of Halstead et al. (1969), who found that increasing organic matter or pH depressed Ni availability. Roth et al. (1971) noted that Cu and Ni toxicity to soybeans influence the P and Fe nutrition of the plant. Cunningham et al. (1975) noted that Cu, Zn and Ni interact to enhance their toxic effects. This work also indicated that, with the crops studied, the relative toxicities of Zn:Cu:Ni were 1:2:1.

It is important to note, however, that to date no documented reports of heavy metal toxicity to crops from sewage sludge application have appeared. This includes the evaluation of long-term disposal sites in Europe and Australia, and the University of Illinois' work in which soils were overloaded by 4.5 to 6.4 times their calculated "Zn equivalence" values (Hinesley, 1974).

(b) **Cadmium in the Food Chain.** The uniqueness of Cd in this group lies primarily in the fact that it is relatively mobile in soil and is not excluded by plants (Lagerwerff, 1974). Since Cd occurs commonly in Zn, Pb-Zn and Pb-Cu-Zn ores at about 0.4% of the Zn content, and has a number of industrial uses, it is being added to the environment at a significant level (Page and Bingham, 1973). Fleischer (1973) estimates that about 90% of the Cd discharged to the atmosphere and streams is from man's activities (Table 17).

The toxicity of Cd to man is well documented (Fleischer et al., 1974; Page and Bingham, 1973; Flick et al., 1971), and its effects are particularly insidious due to the cumulative nature of its deleterious effects on the kidney and liver. Sanjour (1974) reviewed the dietary intake of Cd. He reported results of on-going FDA and Canadian work that the Cd content of foods is typically 0.05 ppm or less. This gives an average dietary intake of 50 to 100 ug of Cd/day for the U.S. population (Table 18; FAO/WHO recommends < 70 μg/day).

As noted in Table 18, cigarette smoking constitutes another major source of Cd. Obviously, further analysis of the Cd level of foods is needed. For example, some shellfish are known accumulators (Sanjour, 1974) and a fish-leafy vegetable diet could constitute a high Cd intake.

The availability of Cd in soils follows closely the principles established for other metals, particularly Zn (for a comprehensive review of factors influencing Zn uptake and availability, see Mortvedt et al., 1972). Species effects are always present (e.g., Page and Bingham, 1972; Bingham et al. 1975) and soil pH is an important variable. John et al. (1972) found that Cd uptake decreased with increasing soil pH, while Lagerwerff (1971) observed that increasing the pH of the soil from 5.9 to 7.2 had no effect on Cd uptake by radishes.

Cadmium may form organic complexes similar to those observed with Zn (Miller and Ohlrogge, 1958), although Haghiri (1974) obtained evidence that soil organic matter interacted with Cd only through exchange reactions. John et al. (1972) found that Cd uptake by plants decreased as soil organic matter content increased.

TABLE 17. *Cadmium emissions to water.*

Source	100 kg per year	% of total
From electroplating	900	44
From other industry	390	19
From sewage (water supply)	490	24
Mines, etc.	?	?
Leaching-agricultural et al.	?	?
Air emissions	250	12
Total	2,030+	

TABLE 18. *Typical American daily Cd intake.*

Source	Concentration	Daily intake (in ug)	Daily absorbed (in ug)
Total diet	0.04 ppm	75.0	4.5
Drinking water	0.0014 ppm	2.8	0.17
Air	0.006 μg/m3	0.12	0.04
Cigarettes (20/day)	---	---	1.5

(c) **Water Contamination.** The extent of contamination of groundwater with heavy metals from sludge application is dependent upon chemical characteristics of sludge, chemical properties of the soil and the distance to the water table. The potential contamination would be greatest where a shallow water table occurred beneath a sandy soil with low organic matter content. Where the water table occurs at the great distances from the surface, the probability of heavy metal contamination of groundwater is greatly diminished.

As further protection, metal uptake by plants can be used to estimate metal mobility and thereby potential for leaching. If metal uptake exceeds established limits, application of metal-laden sludge will be stopped, thereby indirectly protecting the groundwater from metal contamination.

Since heavy metals applied to soil are largely concentrated in the erodible surface soils, runoff and erosion may contribute to heavy metal contamination of waterways. Concentrations of heavy metals in water may have serious harmful effects on certain species of aquatic life. Therefore, surface runoff of sediment into surface waters should be minimized by use of recommended erosion control practices.

The heavy metal content of sludges can be expected to decline, as the waste discharge provisions of PL 92-500 are implemented. This, however, will likely take considerable time and expense.

Recommendations and Calculations of Total Sludge Application Based on Heavy Metals

As an interim guide, U.S. EPA has recommended the following equation to calculate maximum sludge loading in relation to metal toxicity to plants:

$$\frac{32.500 \times CEC}{(ppm\ Zn) + 2(ppm\ Cu) + 4(ppm\ Ni)}$$

where CEC = cation exchange capacity of nonsludged soil in meq/100 g and ppm = sludge metals, mg/kg dry solids. This equation includes a number of conversion factors and is based on the hypotheses that (a) CEC is related to soil factors controlling metal availability in soils and (b) that Cu is 2 times and Ni 4 times as toxic to plants as Zn. It limits metal additions to 10% of soil CEC. There is to date no experimental evidence to support or refute this equation, and it must be regarded as empirical and subject to revision.

The equation is difficult to use because of the inherent variability of sludges with source and time. However, it can readily be modified to permit calculation of total metal loadings on a lbs/A basis as:

65 x (CEC)

where metal equivalents (lb/ton of sludge) are:

$$\frac{(\text{ppm Zn}) + 2(\text{ppm Cu}) + 4(\text{ppm Ni})}{500}$$

The total sludge loading is thus a matter of an accounting of yearly metal equivalent loadings until the maximum permitted is reached.

Table 19 presents an alternative approach where soil CEC values are not available. It estimates metal loadings as a function of clay and organic matter content, and is intended for use in preliminary planning and in small sites where complete soil characterization is not required. However, whenever possible, analytically determined CEC should be used.

In addition to the metal equivalents' limitations, Cd additions must be limited to a maximum of 2 lb/A/yr with a total site lifetime maximum of 20 lb/A. The 2 lb/A recommendation is based on work in Wisconsin showing that, in general, about 2 lb/A of sludge-derived Cd had to be added before a marked increase in Cd content of the vegetative tissue of crops over control values occurred (Tables 20, 21 and 22). These limitations on heavy metal loading based on plant toxicity effects also will protect the ground water from metal contamination due to overloading of sludge on sites which meet the criteria outlined in Section VII.

An example calculation for sludge application rate based on the Zn, Cu, Ni, and Cd content is presented in Figure 4.

TABLE 19. *Estimated total metal equivalent loadings based on soil texture and soil organic matter content.* *

Soil Texture	Soil organic matter content 5-10 tons/A	11-20 tons/A	21-30 tons/A	31-40 tons/A	41-50 tons/A	51-70 tons/A	>70 tons/A
Sand	260	360	490	630	750	940	1140
Loamy sand	330	440	570	700	830	1020	1220
Sandy loam	420	520	650	780	910	1110	1300
Loam	590	680	810	940	1070	1200	1330
Silt loam	750	850	980	1110	1240	1370	1500
Silty clay loam	1240	1330	1460	1590	1720	1850	1980
Clay loam	1400	1500	1630	1760	1890	2020	2150
Clay	2050	2150	2280	2410	2540	2670	2800

*Expressed in total metal equivalents (lb/A). Based on 10% of CEC as (Zn + 2 Cu + 4 Ni); CEC=(0.50) x (% clay) + 2.00 x (% OM). (Helling et al., 1964).

TABLE 21. *Effect of sludge applied on a Waupun silt loam (Arlington Experimental Farm) in 1972 on the uptake of Cd by subsequent crops.* *

Rate of application: Sludge (T/A)	Cd** (lbs/A)	Cd Concentration in Crop (in ppm): 1972-73 Rye***	1973 Corn: Grain	1973 Corn: Stover	1974 Corn: Grain	1974 Corn: Stover
0	0	0.23	0.08	0.15	0.07	0.07
2	0.28	0.25	0.06	0.20	0.07	0.10
4	0.56	0.35	0.07	0.18	0.07	0.07
8	1.12	0.45	0.07	0.25	0.07	0.16
16	2.24	0.40	0.02	0.25	0.07	0.13
32	4.48	0.50	0.05	0.27	0.19	0.13

*Sludge was applied only in the summer of 1972.

**The Cd content of the sludge was 70 ppm.

***Rye was planted in the fall of 1972 and harvested in May of 1973. Corn was planted following harvest of the rye.

TABLE 20. *Effect of sludge applied on a Waupun silt loam (Arlington Experimental Farm) in 1971 on the uptake of Cd by subsequent crops.* *

Rate of application: Sludge (T/A)	Cd** (lbs/A)	Cd Concentration in Crop (in ppm): 1971-72 Rye***	1972 Corn: Grain	1972 Corn: Stover	1973 Corn: Grain	1973 Corn: Stover	1974 Corn: Grain	1974 Corn: Stover
0	0	0.10	0.09	0.03	0.06	0.08	---	0.07
2	0.28	0.25	0.09	0.06	0.05	0.05	---	0.07
4	0.56	0.30	0.13	0.04	0.05	0.09	---	0.07
8	1.12	0.25	0.08	0.09	0.08	0.07	---	0.07
16	2.24	0.30	0.11	0.25	0.05	0.25	---	0.07
32	4.48	0.30	0.09	0.30	0.05	0.24	---	0.07

*Sludge was applied only in the summer of 1971.

**The Cd content of the sludge was 70 ppm.

***Rye was planted in the fall of 1971 and harvested in May of 1972. Corn was planted following harvest of the rye.

TABLE 22. *Effect of sludge applied on a Waupun silt loam (Arlington Experimental Farm) in 1973 on the uptake of Cd by subsequent crops.* *

Rate of application: Sludge (T/A)	Cd** (lbs/A)	Cd Concentration in Crop (in ppm): 1973 Sorghum-Sudan	1974 Corn: Grain	1974 Corn: Stover
0	0	0.53	0.07	0.07
2	0.28	0.50	0.07	0.19
4	0.56	0.75	0.07	---
8	1.12	0.75	0.07	0.13
16	2.24	0.85	0.07	0.13
32	4.48	0.95	0.12	0.19

*Sludge was applied in May and June of 1973.

**The Cd content of the sludge was 70 ppm.

Example calculation:

Sludge metals(ppm); Zn = 5,300; Cu = 1,300; Ni = 900; Cd = 100. Application site soil CEC= 10 meg/100 g soil.

(1) Total metal equivalent loading = 65 X CEC = 650 lb/A

(2) Sludge metal equivalent per ton = $\frac{5{,}300 + 2(1{,}300) + 4(900)}{500} = \frac{11{,}500}{500}$

= 23 lb metal equivalents per ton of sludge

(3) Total loading permitted = $\frac{650}{23}$ = 28.3 tons

(4) Yearly loading limit due to Cd = $\frac{2 \times 500}{\text{ppm Cd}} = \frac{2 \times 500}{100}$ = 10 tons/A for 2 lb. of Cd.

(5) Total Cd loading permitted = 20 lb/A = 100 tons/A

Therefore, Cd loading is limiting on a yearly basis (10 tons/A/year) while metal equivalents (Zn, Cu and Ni) are limiting on the lifetime of the site (28.3 tons/A).

FIGURE 4. *Calculation of sludge application rate based on metals loading.*

III. SLUDGE APPLICATION SYSTEMS AND EQUIPMENT

Three interdependent phases of sludge handling for land application can be identified (White et al., 1975). These are (a) type and quantity of sludge produced, (b) transportation and storage, and (c) application. The degree of treatment affects both transportation and application modes directly since slurry (liquid) sludges have much different handling characteristics than the cake (solid) materials.

Sludge Production and Treatment

Farrell (1974) estimates daily per capita sludge production as primary, 0.12 lb; primary plus secondary, 0.20 lb; primary plus secondary plus chemical, 0.25 lb. Thus, a city of 10,000 without any industries and with a secondary treatment plant would produce about 365 tons of dry solids yearly, or at 4% solids, 9,125 wet tons (2.2 x 10^6 gallons). On the other hand, the Metropolitan Sanitary District of Greater Chicago produced over 800 tons of solids per day in 1973 (Graef, 1974). These two extremes illustrate the fact that different sludge disposal systems will be needed depending on quantities of sludge produced.

Transport and Storage

The physical characteristics (solids content) of the sludge will be a primary factor influencing the type of transportation and application equipment selected. If the slurry has a solids' content of up to 8%, it may be easily pumped. When the sludge is dewatered to a solids' content of 15% or higher, it must be handled as a solid material (White et al., 1975). Table 23, adapted from White et al. (1975), outlines the transport modes that are available. Selection will also depend on production rate, distance to application site, proximity to railway, seasonality of application and planned lifetime of the site.

Pipelines, especially buried pipelines, are probably uneconomical for small communities. Tank trucks provide considerable flexibility with regard to site selection and hauling schedule and have the additional advantages that liquid sludge can be applied directly from the truck (Figs. 5, 6 and 7). They have the disadvantage of not being suited, unless modified with flotation tires, to adverse weather and soil conditions. Gravity discharge is most commonly used, although pressurized tanks or pumps can be used to increase the rate of discharge (Fig. 8). Also, settling of solids during transport has been a problem, and some method of agitation might be required to resuspend solids after long hauls.

Dewatered sludge should not be allowed to air-dry before storage. Experience with the Imhoff-process dewatered sludge at Oshkosh has shown that this sludge forms an extremely hard cake on drying, and considerable effort is required to break up the cake for loading and application.

Due to the inclement weather, frozen soil and snow cover which exist during Wisconsin winters, as well as variations in sludge production and the possibility of equipment breakdown, some storage facilities must be provided. These are usually tanks or lagoons, and if room is available, should be at the treatment site due to the maintenance and public acceptance problems which may occur if extended storage is required at the disposal site. Some provision for resuspension of settled solids must be provided.

Field Application

The application method or methods chosen will depend on factors such as physical properties and quantity of sludge, application rate, site characteristics and management, crop grown, and public acceptance.

Systems are available for surface and for subsurface (plow-down or injection) application of sludge (Table 24 and Figs. 9 to 15). The product file issue of *Implement and Tractor Magazine* provides an annual listing of irrigation and tankwagon manufacturers. Surface application of liquid sludge is generally accomplished by spray (Fig. 16), ridge and furrow irrigation or by tank truck (Fig. 5-7) or farm wagon. Due to the requirement that sludge be applied to soils at fertilizer rates, fixed irrigation systems such as a center pivot system, would most likely be uneconomical. Portable irrigation systems using a single large-nozzle gun (3/4-inch to 2-inch orifice) at 80 to 100 psi have been used (Fig. 16). Spray irrigation has the possible, but not proven, disadvantage of aerial pathogen contamination, and is not suited for use with sludges and/or locations where odor, either real or imagined, is a problem. Further, runoff is a potential problem unless the site is carefully managed, and plant damage may result if sludge is sprayed on growing crops.

Ridge and furrow irrigation requires prior preparation of the land, and only relatively level land can be used. It has the advantage that it is suitable for row crops during the growing season.

To date, the most commonly used surface application methods, especially by smaller communities, are the tank truck and farm tank wagons. The tank truck has the advantage that it can also be used for sludge transport, but use of either a truck or a wagon requires suitable soil conditions. Further, they cannot be used on row crops, and experience at Janesville has shown that tank truck traffic severely damaged established alfalfa stands within one year.

Soil incorporation of liquid sludge has a number of advantages over

TABLE 23. *Sludge transport methods.* *

Sludge State and Mode of Transport	Characteristics	Comments
Liquid		
Rail Tank Car	Capacity, 100 wet tons (24,000 gal.). Need loading and disposal sites near RR.	Solids will settle while in transit; some form of agitation desirable.
Fixed Pipeline (buried)	Suitable for year-round use.	As diameter of pipe increases, pressure loss due to friction decreases (inversely proportional to pipe diameter to the fifth power). Need minimum velocity of 1 f.p.s. to keep solids in suspension. High capital costs.
Portable Pipeline (surface)	Will freeze if used intermittently, not suitable for winter use unless provision made for draining.	Use at disposal site to provide flexibility in selecting field for disposal.
Tank Truck	Capacity, 500 gal. up to maximum allowed on road. Can have gravity discharge or forced (pressure or pump) discharge.	Can use for highway transport and field application. Can use large tractor trailer rig for highway transport but must transfer for field application. If flotation tires used for field travel, not recommended for long distance highway travel.
Farm Tractor and Tank Wagon	Capacity, 800 to 3,000 gal.	Low speed; principal use would be field application, not distance hauling.
Solid		
Rail Hopper Car	Need special unloading site and equipment for field disposal.	Possible use when final disposal is of landfill type. Sludge can be flushed from cars to a lagoon for disposal as a slurry.
Trucks, dump or other type	Suitable for wastes or sludges in solid, nonslurried form.	Trucks can be fitted with equipment to spread waste on ground surface. If dump truck used, will need to level sludge piles. Soil incorporation desirable.
Farm Wagons or Manure Spreaders	Suitable for wastes or sludges in solid, nonslurried form.	Principal use would be field application, not distance hauling. Soil incorporation desirable.

*Adapted from White et al., 1975.

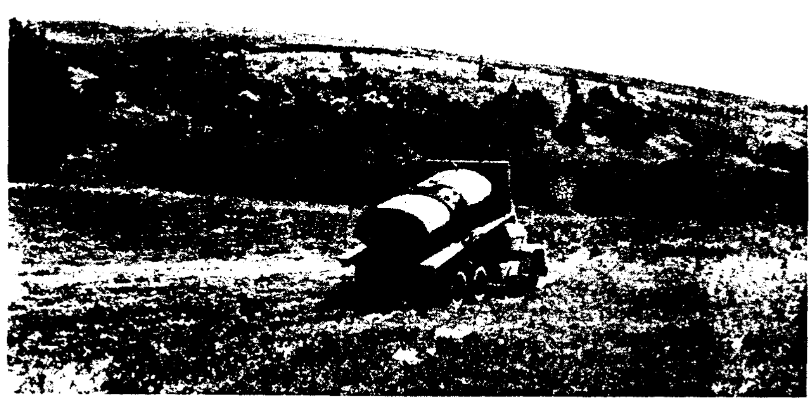

FIGURE 5. *Elevating tank to give more uniform discharge and remove solids (Pullman, Wash., 1972).*

FIGURE 6. *Discharging slurried waste in narrow swath from a tank wagon.*

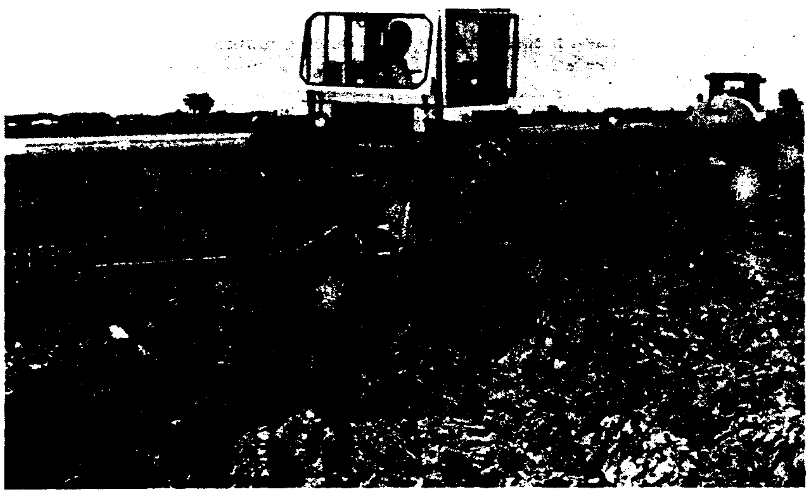

FIGURE 7. *Immediately covering discharged waste with a four-moldboard plow.*

FIGURE 8. *Commercial tank truck with pump discharge. Courtesy of Gorman–Rupp Co., Mansfield, Ohio.*

surface application. Odors and pests are not a problem, N is conserved since ammonia volatilization and runoff are minimized, and public acceptance may be better. It must be remembered that the soil depth requirement to be presented in Section VII (Table 28) of 2-4 feet for moderate limitations and >4 feet for slight limitations is measured at the depth of application. Thus, for example, injection to 1 foot reduces the soil depth by this amount.

Soil incorporation of liquid sludge can be done in a number of ways. The main methods used are plow-furrow-cover (Fig. 7) and subsurface injection (Figs. 9-15). Reed (1974) has described developments in New Jersey on this equipment, and has had particular success with the plow-furrow-cover method. This approach involves discharging the sludge in a narrow swath from a wagon and immediately covering the waste with a plow. This approach is obviously tied to season, weather and soil conditions, and is best suited for high loading rates (a minimum of 8 to 10 dry tons/A of 5% slurry). Other tillage methods which adequately incorporate the sludge may be suitable (e.g., disc or chisel), but reports of successful use of these have not appeared to date.

Subsurface injection tillage involves a tool such as a chisel or sweep to open a channel in the soil, and the liquid then flows into the opening, either by gravity or under pressure. It may be necessary to use pressure to close the channel, and normally the waste takes considerable time to dissipate into the soil. Our experience has been that a waiting period of 1 to 2 weeks after the injection is required before a vehicle can be driven over the injection site.

Several manufacturers offer liquid animal manure handling systems which have been found suitable for sludge application. Colorado State University (at Boulder) has developed a subsurface injection system (Smith, 1974), which involves a crawler tractor as the prime mover and a flexible hose to supply sludge from the field perimeter. This unit is capable of delivering from 4 to 16 tons of solids/A at 5% solids. It has 7 injector sweeps covering about 10 feet. Most commercial units have 2 to 4 injectors mounted on a tool bar, and some can be used to sidedress crops.

Reed (1974) has developed an injection plow system in which the landsides of a right-hand and a left-hand plow were fastened together, and the

TABLE 24. *Field application methods.* *

Sludge State and Mode of Transportation	Characteristics	Topographical and Seasonal Suitability	Comments
Liquid (Surface Application)			
Irrigation Spray (sprinkler)	Large orifices required for nozzle. Large power requirement. Wide selection of commercial equipment.	Can be used on rough or steep land. Can be used year-round with provision for draining in winter. Not suitable for application to some crops during growing season. Sludges must be flushed from pipes when irrigation stops.	Application rate not recommended to be over 1/4 in/hr.; less if runoff begins to occur. Permanent irrigation set can be used on pasture and woodlands.
Ridge and Furrow irrigation	Less power requirement than spray irrigation. Land preparation needed.	Between 1/2 and 1-1/2% slope, depending on percent solids. Can be used in furrows between row crops during growing season. Can be used year-round with provision for draining pipes in winter.	
Tank Truck	Capacity, 500 to 2,000 gallons. Larger volume trucks require flotation tires.	Smooth and level or slightly sloping land. Not usable with row crops or on soft ground.	Can be used for transport and disposal.
Farm tractor and Tank Wagon	Capacity 800 to 3,000 gals.	Smooth and level or slightly sloping land. Not usable with row crops or on soft ground.	
Liquid (Subsurface Application)			
Tank Truck with Plow Furrow Cover	Capacity, 500 gals. Single furrow plow mounted.	Smooth and level or slightly sloping land. Not usable on wet or frozen soil.	Not suitable for long transport.
Farm Tractor and Tank Wagon Plow Furrow Cover	Sludge discharge into furrow ahead of single plow. Sludge spread in narrow swath and immediately covered with plows.	Smooth and level or slightly sloping land. Not usable on wet or frozen soil.	Additional tractor power needed to pull plow.
Subsurface Injection Equipment	Sludge placed in channel opened by tillage tool.	Smooth and level or slightly sloping land. Not usable in wet, hard, or frozen soil.	Additional tractor needed to pull tillage tool. Vehicles should not traverse injected area for a week or more.
Solid			
Spreading, either truck mounted or farm spreaders	Waste spread evenly over ground. Normally followed by soil incorporation, disking or plowing. Use plow or disc large enough to give complete coverage.	Very light applications (less than 2 dry tons/acre) need not be incorporated unless surface runoff is likely to occur.	
Reslurry and handle as liquid sludge		Suitable for long hauls where rail transport is available.	

*Adapted from White et al. (1975).

liquid waste transferred through a 6-inch pipe to the cavity created by the plow. This system has potential for applying sludge to sod, park lands and roadways as well as agricultural land.

Commercially available pull and truck mounted box-type manure spreaders are available for application of dewatered sludge (Fig. 17). Incorporation should be by conventional disc, chisel or mold board plow.

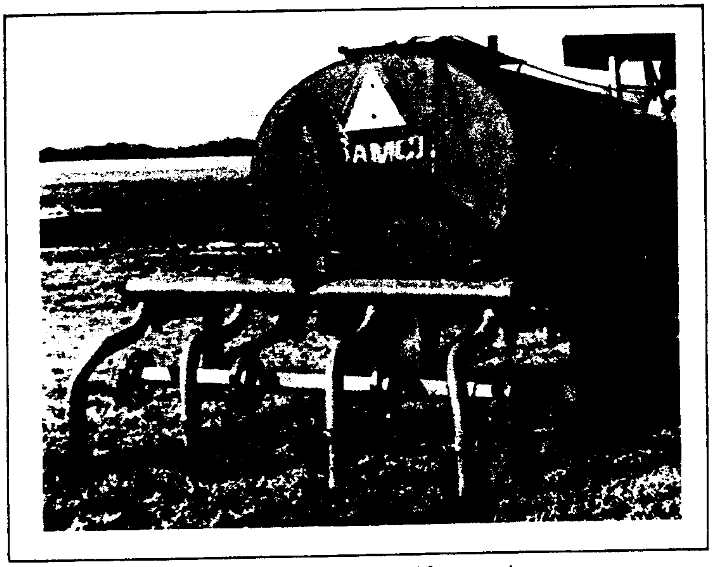

FIGURE 9. *Tank wagon injecting liquid waste into soil.*

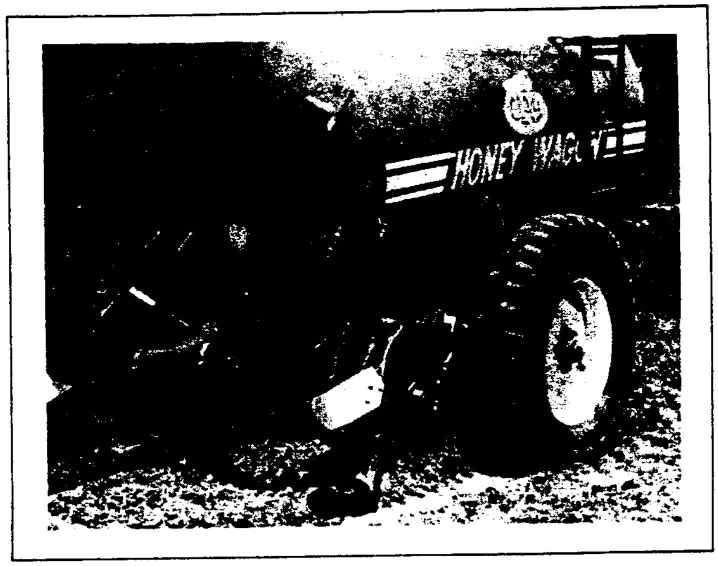

FIGURE 10. *Tank wagon with sweep-shovel injectors.*

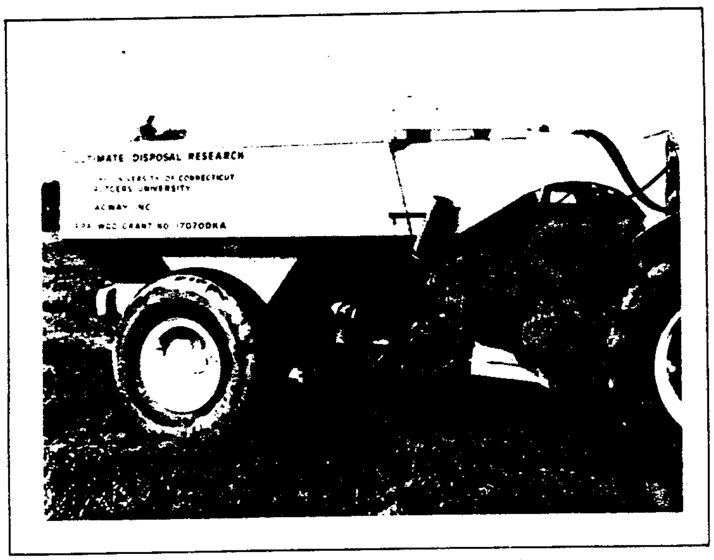

FIGURE 11. *Second type of injection plow with 1,000-gal. tank trailer with gooseneck tongue. Injector mounted on three-point hitch of tractor. Courtesy of C.H. Reed, Rutgers University.*

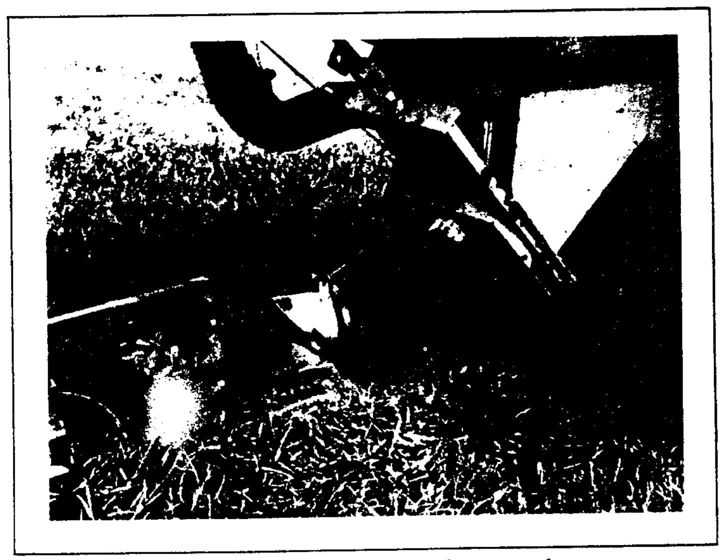

FIGURE 12. *Sub-sod injection plow in the ground. Courtesy of Prof. C.H. Reed, Rutgers University.*

FIGURE 13. *Sweep-shovel injectors with covering spoons.*

FIGURE 14. *Sub-sod injection plow made from mold boards.*

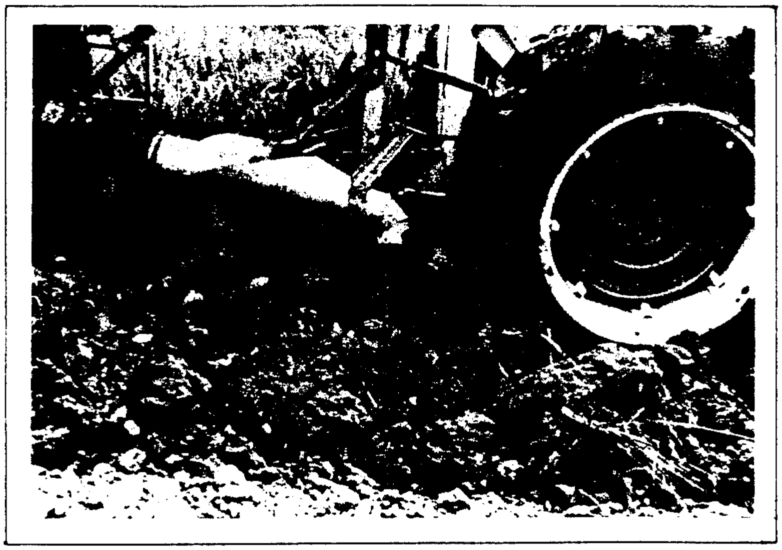

FIGURE 15. *Covering of slurried waste with a single, moldboard plow. Courtesy of Prof. C.H. Reed, Biological and Agricultural Engineering, Rutgers University.*

FIGURE 16. *Big gun nozzle for portable irrigation system.*

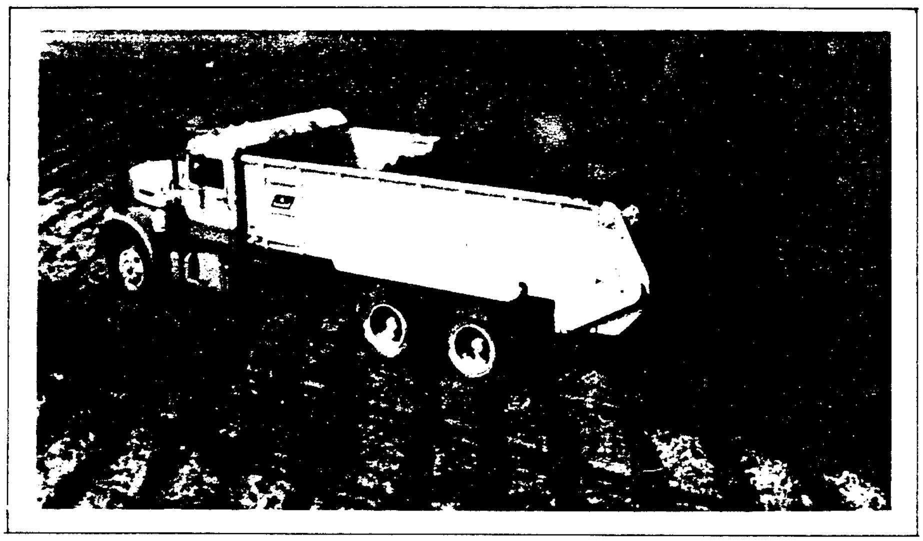

FIGURE 17. *Large, commercial spreader. Courtesy of BJ Manufacturing Co., Dodge City, Kan.*

IV. ECONOMICS OF SLUDGE APPLICATION TO LAND

The economics of sludge application to land is a very dynamic and difficult situation to evaluate. It is affected not only by general economic conditions but also by technological advances in sludge handling and legal constraints imposed by regulatory agencies for adequate public health and environmental protection.

At present, and in the foreseeable future, the municipality or sanitary district should regard sludge as a liability and design its handling system around the least-cost acceptable means of disposal. The acceptable alternatives at present include landfilling, permanent lagoons, incineration and land application.

Landfilling expenses include costs of site acquisition and operation, and the energy and equipment costs of dewatering and transport. Protection of groundwaters from N, P and metal contamination from this material must be evaluated in any economic consideration. The analysis by Ewing and Dick (1970) is the most recent study to consider the available alternatives. Their results indicate that, as of about 1966 and before the marked increase in fuel costs and implementation of the Clean Air Act to control emissions from incinerator stacks, the relative cost per ton of sludge for landfilling was about twice that of land application and one-half that of incineration without adding in transportation costs. For cities of 100,000 or less, the point where landfilling became cheaper than land application was about 25 miles of transport to the disposal site.

The economics of incineration for further solids reduction before disposal of the ash in a landfill is greatly affected by cost and availability of fossil fuels. Incineration reduces the solids content by 60 to 65%, but requires much fuel in order to burn the high water content sludge. Lue-Hing et al. (1974) estimate that, for the Metropolitan Sanitary District of Greater Chicago, the cost of incineration is about \$90 to \$100 per dry ton exclusive of emission control costs. About 50 gallons of fuel oil on the average are required to combust one ton of sludge. Lue Hing et al. (1974) estimate 900 million gallons of oil would be required yearly to incinerate all the sludge produced in the U.S. In addition, fertilizer nutrients, particularly N, are lost.

Other alternate disposal systems include sludge composting with wood chips, composting of sludge and solid waste mixtures, incineration of sludge and solid waste and pyrolysis or anaerobic digestion to recover methane. Some of these operations are in the experimental stage at the moment, and due to high capital and operating costs, many probably will not prove economical for smaller municipalities.

Sludge composting with added wood chips as the carbonaceous source is being evaluated in an extensive study at Beltsville, Maryland (Walker, 1973). Intital results are quite promising, and a 250-ton-per-day capacity is anticipated. The economics of this approach have not been reported. However, the final product is pathogen-free, odorless, and an excellent soil amendment. Other composting systems using solid wastes (garbage) as the carbon source are feasible and may be economical.

Evaluation of the economics of a land application system must take into account all facets of the operation. White et al. (1975) have summarized these alternatives in a flow-diagram model with all possible alternatives. Their conception has been simplified in Figure 18.

Steps 1 and 2 are largely dictated by in-plant economics and design, while storage is dependent on sludge pretreatment and available space. Transportation costs to the disposal site can represent a significant portion of the disposal cost. Bauer (1973) estimated trucking costs of about \$0.10/wet ton/mile. Lagooning will likely be the least expensive storage method at the site. Land application costs will vary depending on the methods chosen. Bauer (1973) estimated that lagooning of sludge at the treatment plant, followed by trucking of the partially dewatered (15% solids) material 20 miles and applying the sludge to land would cost \$48.30 per dry ton. At 5% solids (no dewatering) the corresponding cost would be \$59.90 per ton.

The fertilizer value of the sludge must also be included in a benefit-cost analysis. Since sludges do have wide variance with respect to their N, P and K contents, average figures would be misleading. However, for an example, at an "available" analysis of 3.5% N, 11.1% P_2O_5 (5% P) and 0.57% K_2O (0.48% K), the current fertilizer value of a sludge would be about \$63.00 per dry ton (1974-75 prices of 25, 20 and 8 cents/lb of N, P_2O_5 and K_2O).

1. Raw Sludge
↓
2. Liquid Digested Sludge → De-watered sludge
↓
3. Storage
↓
4. Transportation → Storage
↓ ↓
5. Land Application

FIGURE 18. *Flow-diagram model showing all stages in sludge treatment and application.*

V. PUBLIC ATTITUDES AND ACCEPTANCE OF LAND APPLICATION

The late 1960's and early 1970's saw several reasonably well-designed land application systems that met with strong public criticism. Brooks (1974) and Bevins (1974) discussed this problem in a regional workshop, "Educational Needs Associated with the Utilization of Wastewater Treatment Products on Land." Brooks pointed out that sociologists have not been involved with these types of projects in the past, and that the available technology is far ahead of our knowledge of the societal effects. He also pointed out that much of the general public, through years of health education, perceives all human by-products as unsanitary, i.e., that these by-products cannot be used for anything useful under any condition. Even when this resistance is overcome, the general concern about aesthetics may limit public acceptance.

Resistance to change (i.e., acceptance of a land disposal system) is often great in rural communities due to the autonomy of the farmers, and conformity to the norms of the social group (Brooks, 1974). In developing programs for a sludge-use program, "grass roots" support is essential. Obtaining this support involves extensive education programs coupled with explanation of the product involved, definition of terms used, benefits and risks, and small-scale demonstration plots.

Bevins (1974) offered the policy approach or format by which educators and public officials can minimize heated conflicts on a controversial project. These are: (1) define the problem; (2) consider goals and objectives; (3) develop alternative solutions; (4) explore the consequence of alternatives; and (5) leave the decision of alternative selection to the people.

Defining the problem

This is a difficult step. The community may see the problem as disposal of wastes, while the people in the receiving area may view the problem as receiving unwanted materials. The problem must be identified so all groups can identify with the statement (e.g., a long-term waste management system for the area).

Identifying the goals and objectives

Identifying goals involves thinking through the views of the various people and groups involved, and expressing these in terms of what (not how) goals should be accomplished.

Identifying alternate approaches

Example alternatives might include to : take no action; develop an incineration system; apply sludge to land; lower the environmental standards; or some combination of these.

Evaluating alternatives

In evaluating the alternatives, public reaction, group conflicts, vested interests, economics and environmental benefits must be evaluated in terms of positive statements, i.e., refrain from becoming an advocate of a certain position. As much as possible, this evaluation should include second and third order effects such as effects of taking land out of production or off the tax roles on the economy of the region or effects of a waste disposal operation on land values.

VI. HEALTH ASPECTS OF SLUDGE APPLICATION TO LAND

The public concept that wastewaters and sludges are "dirty," "impure" or "unhealthy" can be one of the major deterrents to acceptance of a land application program. This is especially true with systems using surface application, where mere sight of the waste brings a conditioned response. Since waste processing as practiced currently in most sewage treatment plants does not render the sludge completely free of pathogenic organisms, sludge must always be handled with caution.

The pathogenic agents found in wastes can be classified in four groups: viruses, bacteria, protozoans and intestinal worms (helminths) (Burge, 1974). The adult forms of the latter two perish quickly external to their hosts, while the cysts of protozoans and the ova of the helminths are capable of survival and are very persistent in wastes. The sludges produced by primary and secondary processes may contain all four groups of pathogenic agents, including *Salmonella*, tubercle bacilli, *Endamoeba*, ascarids, and hookworms. Fortunately, spore-forming bacteria such as *Clostridium tetani* and *Bacillus anthracis*, which are very persistent in soil, do not occur in sewage wastes (Burge, 1974).

Methods for disinfecting sludge include pasteurization, composting, heat drying and lime treatment (Farrell, 1974). Chlorination cannot easily disinfect sludges because of their solid nature. Pasteurization implies heating to a specific temperature for a time period that will destroy undesirable organisms in sludge. While pasteurization at 70°C for 30 to 60 minutes is effective for digested sludge, it is an expensive process. The addition of lime in sufficient quantities to maintain a high pH (between 11.0 to 11.5) destroys pathogenic bacteria. By liming, *Salmonella* and *Pseudomonas* were totally eliminated, and >99% of the fecal coliform and fecal streptococci were destroyed (EPA, 1974). The addition of lime, however, is expensive and significantly increases the amount of sludge to be disposed of. Composting and heat drying can be effective means of destroying pathogens, but costs, energy requirements and marketing requirements restrict the use of these methods.

Anaerobic digestion is a highly effective process for reduction of fecal coliforms. Virus levels are also greatly reduced by anaerobic digestion (MSDG Chicago, 1974). Figure 19 shows the reduction of a bacterial virus (coliphage) and an enteric virus. About 90% of the virus were inactivated in 24 hours and 99% in 48 hours. Molina et al. (1974) observed that the activated sludge process inactivated 99% of the poliovirus in sludge in 24 hours. The reviews by Ewing and Dick (1970) and Dean and Smith (1973) cited references indicating that fecal coliform, (*Salmonella*, *Pseudomonas* and *Endamoeba histolytica)* populations have a high die-off rate in aerobic and anaerobic digestors.

The most acceptable, effective and economically feasible method for pathogen reduction may prove to be prolonged sludge storage. Table 25 shows the fecal coliform decline resulting from the storage of liquid digested sludge (MSDG Chicago, 1974). After seven days of lagooning, the coliform decline was 99% of the original. The rapidity with which many pathogenic organisms die away after digested sludge is applied on the soil is shown in Table 26. After seven days of drying, the number of fecal coliforms declined to less than 1% of the one-day counts (Lue-Hing et al., 1974). However, Moe (1974) observed that, even 25 days after application of sludge from the Menominee Falls plant to a poorly drained Blount silt loam, fecal coliform counts remained high. This work was conducted during the summer and the plot area received considerable rainfall. Therefore, it would appear that sufficient precautions should be taken to minimize human contact with sludge and limit public access to disposal sites.

From laboratory studies, Berg (1966) determined the time required for 99.9% reduction in the number of viruses and bacteria by storage at different temperatures (Table 27). At 20°C, 41 days were sufficient. Lue-Hing et al. (1974) concluded that an

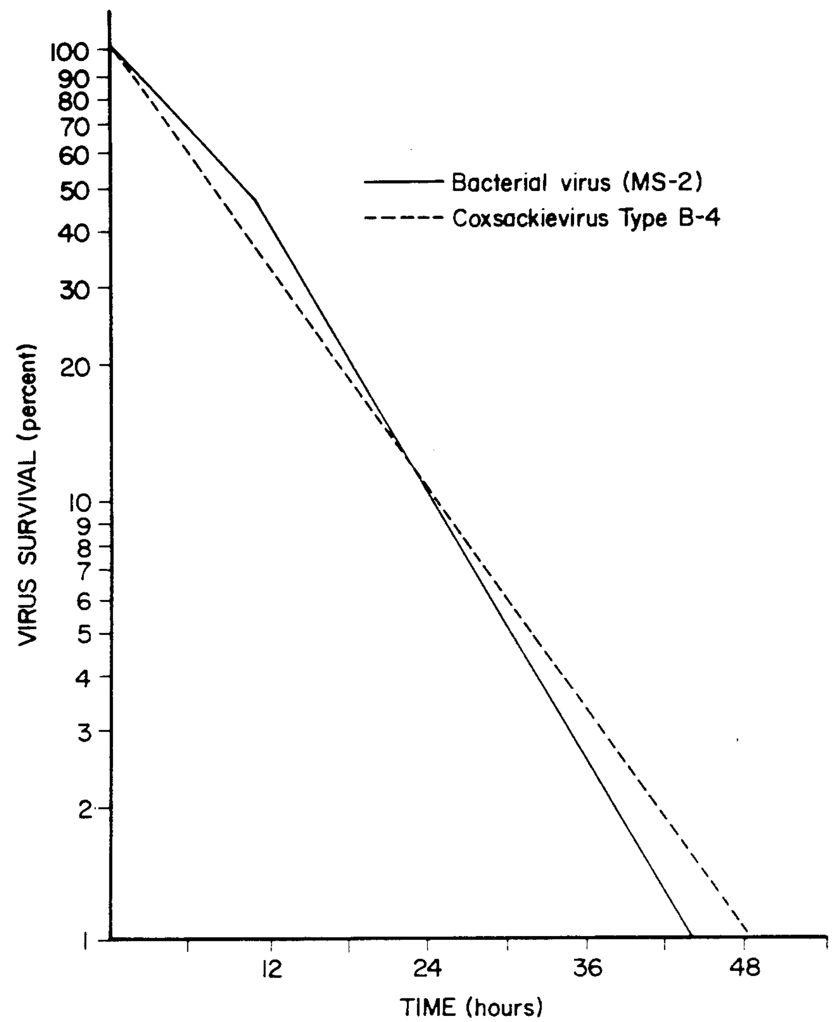

FIGURE 19. *Inactivation of viruses with time in anaerobically digesting sludge (MSDG Chicago, 1974).*

TABLE 25. *Fecal coliform counts of stored digester supernatant exposed to atmospheric conditions (MSDG Chicago, 1974).*

Days	Fecal Coliform Counts (per 100 ml)	Percent Survival
0	800,000*	100.00
2	20,000**	2.50
7	8,000	1.00
14	6,000	0.75
21	<2,000	<0.25
35	<20	<0.01

*Fecal coliform count just prior to lagooning.
**Fecal coliform count after lagooning.

TABLE 26. *Disappearance of fecal coliforms in sludge cake covering a soil surface (Lue-Hing et al., 1974).*

No. Days after Sludge Application	No. of Fecal coliforms per gm Sludge Cake (Dry Weight)
1	3,680,000
2	655,000
3	590,000
5	45,000
7	30,000
12	700

TABLE 27. *Laboratory study on days of storage required for 99.9% reduction of virus and bacteria in sludge (Berg, 1966).*

	No. of days at		
Organism	4^0C	20^0C	28^0C
Poliovirus 1	110	23	17
Echovirus 7	130	41	28
Echovirus 12	60	32	20
Coxsackievirus A9	12	---	6
Aerobacter aerogenes	56	21	10
Escherichia coli	48	20	12
Streptococcus faecalis	48	26	14

additional margin of safety against pathogens could be achieved by holding digested sludge in reservoirs for at least two months before it is applied on land.

Pathogens are readily removed by soils through filtration, sorption-inactivation and die-off, and their movement is usually limited to within a few feet from the source, unless soil is of very coarse texture or contains cracks and channels.

In general, it appears that there is little evidence for the dissemination of disease to humans or animals by land spreading of digested sewage sludge. To insure surface water and groundwater protection from pathogenic organisms which might survive the digestion and storage period, conservation practices of avoiding runoff are recommended for the management of sludge disposal sites.

From the available data, we recommend:

1. Raw sludge should not be applied to agricultural land.

2. At least 2 feet, and preferably greater than 4 feet of soil exist between the sludge application zone and bedrock, any impermeable layer, or the water table.

3. Sludge should not be applied to soil in the year the soil is used for any root vegetables, or other vegetables that are consumed uncooked.

4. If sludge is surface applied, runoff should be minimized by use of contour strips, terraces, and border areas. Also, runoff can be reduced by injection or immediate incorporation of the sludge.

5. Pasture land should not be grazed by milk cows for at least two months after sludge application. Other animals should not graze pasture land for at least two weeks after sludge application.

6. Green-chop forage should not be fed to milk cows for two months or to other animals for at least two weeks after sludge application.

7. To ensure adequate protection of water supplies, the sludge application site should be a minimum of 1,000 ft from the nearest public water supply well and 500 feet from the nearest private water supply well.

VII. SITE SELECTION

Communities planning systems for land application of sewage sludge will have to consider a number of factors. These include: (1) location relative to the treatment plant to minimize transportation distance; (2) availability of sufficient land in relation to local and regional land use plans, desirability of private farmer vs. short- or long-term lease *vs.* outright land purchase; (3) need for on-site storage facilities; (4) population density; and (5) soil suitability. The first four factors are quite objective, and when considered in total with their political and economic ramifications, will likely restrict considerably the availability of sites. The sites remaining must be subjected to a number of suitability criteria with the ultimate aim of choosing the most suitable sites in relation to landscape and soil properties. Oftentimes the available sites will not be ideal. Therefore, some flexibility in requirements must be maintained. In most cases, some site alteration and careful management practices will overcome the potential objections to the site. On-site inspection by qualified personnel should be conducted to evaluate the site in relation to the management system being proposed. Assistance can be obtained from a number of organizations including: the U.S. Soil Conservation Service; the University of Wisconsin Department of Soil Science and Cooperative Extension Service; the Wisconsin Geological and Natural History Survey; professional consultants; and the Wisconsin Department of Natural Resources.

The basic objective of a sludge application system is to maximize nutrient utilization and minimize environmental problems. With regard to the site chosen, landscape features and soil properties must be evaluated. The most restrictive property is then used to provide a suitability rating. These ratings are given with regard to limitations to use of the site for sludge application at nitrogen fertilizer rates. They are defined as: slight (no limitations or limitation easy to overcome), moderate (limitations can be overcome with average management), or severe (limitations are difficult to overcome). The criteria used are summarized in Table 28. Appendix A gives the suitability ratings for the major soil series in Wisconsin.

Landscape Properties

Many soils are underlain by horizons that are less permeable to water than is the surface soil. This can be due to increases in the clay content of the horizon or compaction due to plowing. When water reaches these layers, it can move laterally downslope and discharge later as a surface spring or seep, or move to the water table and reach a more permeable layer. These situations must be evaluated by a hydrologist.

Soils and landscapes are quite complex, and within an area of uniform parent material, soils can differ markedly due to differences in drainage. Soils on ridge tops and steep slopes are well drained, well oxidized, usually thinner, and subject to erosion. Soils on concave land positions and on broad flats are more poorly drained, receive water and sediment from soils higher on the landscape, and commonly have an accumulation of organic matter and clay and waterlogged conditions part of the year. The soils between these two extremes will have intermediate properties with respect to drainage and organic matter accumulation.

Soil Properties

Soil texture, organic matter content and pH are probably the most important soil properties. Texture is defined as the relative proportion of sand, silt and clay in the soil material, and for convenience has been divided into 12 groupings (Fig. 20). In most soils, the clay fraction represents only about 10 to 40%, and the organic matter only about 2 to 10% of the total soil. However, because of the colloidal nature and hence large reactive surface areas of these materials, they govern most of the physical and chemical reactions in the soil.

Soils high in clay often contain much more pore space (the volume of soil not occupied by solids, which usually is in the range of 30 to 60%), but these pores are very small and transmit water slowly. Also, the clay tends to swell when wetted, and thus any cracks or channels which may be present seal when water is added. Therefore, the infiltration rate on soils high in clay is quite low, especially if the rain is of very high intensity. This favors runoff and erosion from the

TABLE 28. *Soil limitations for sewage sludge application to agricultural land at nitrogen fertilizer rates.* *

Soils Features Affecting Use	Degree of soil limitation: Slight	Moderate	Severe
Slope**	Less than 6%	6 to 12%	More than 12%
Depth to seasonal water table	More than 4 ft.	2 to 4 ft.	Less than 2 ft.
Flooding & ponding	None	None	Occasional to frequent
Depth to bedrock	More than 4 ft.	2 to 4 ft.	Less than 2 ft.
Permeability of most restricting layer above 3 feet	0.6 to 2.0 in/hr	2.0 to 6.0 in/hr 0.2 to 0.6 in/hr	Less than 0.2 in/hr More than 6 in/hr
Available water capacity	More than 6 in.	3 to 6 in.	Less than 3 in.

*The assistance of A.J. Klingelhoets, USDA-SCS is gratefully acknowledged.

**Slope is an important factor in determining the runoff that is likely to occur. Most soils on 0 to 6 percent slopes will have very slow or slow runoff; soils on 6 to 12 percent slopes generally have medium runoff; and soils on steeper slopes generally have rapid to very rapid runoff.

landscape. Further, surface application of sludge effectively seals soil pores. The general experience has been that surface-applied sludge does not infiltrate into soil and that it will effectively prevent any infiltration. Thus, control of runoff is imperative, even on coarse-textured soils.

The rate of water movement through soils is also an important factor as this governs the residence time of soluble materials in the root zone. When quite moist, sandy soils, due to their large pores, transmit water very rapidly. This coupled with the fact that sandy soils are low in clay (by definition) and usually low in organic matter, makes them poor choices for sludge disposal.

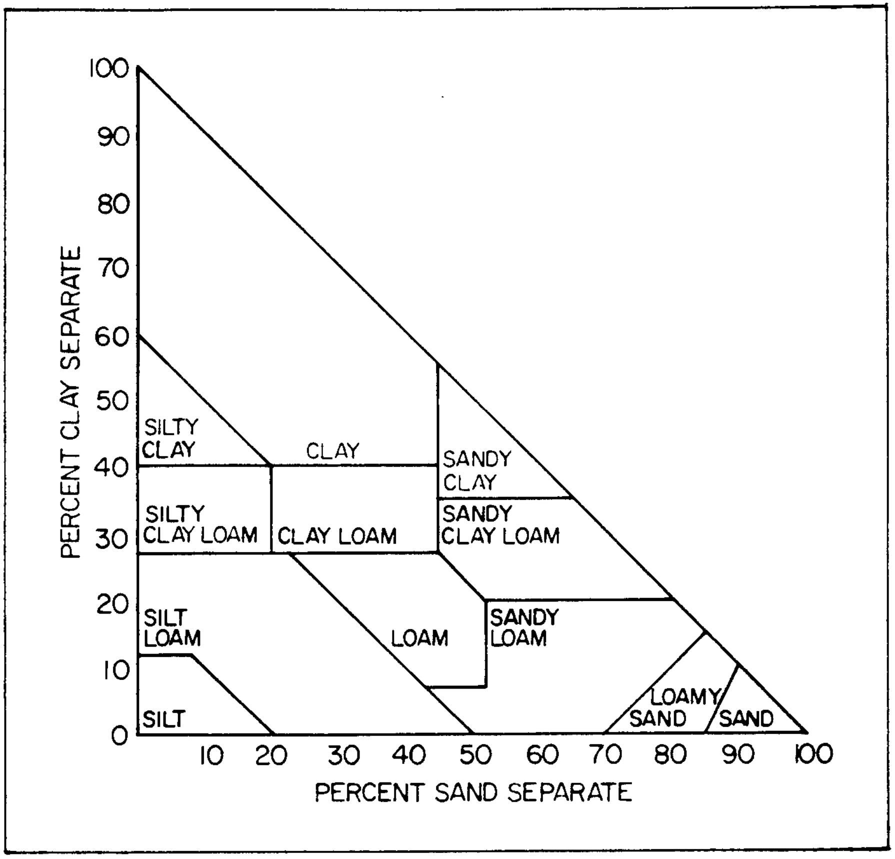

FIGURE 20. *Diagram for determining soil textural classes based on the particle-size classification of the U.S. Department of Agriculture. A point representing the percentages of clay and sand in a soil is plotted on the graph in the normal manner. The labeled area in which the plotted point falls identifies the textural class name of the soil.*

VIII. SITE MANAGEMENT

The sludge application site(s) must be managed to minimize: (1) risks of nitrogen, phosphorus and pathogen contamination of surface and ground waters; (2) risks of soil degradation by metal overloading and of toxic metal uptake by crops; (3) risks of pathogen transmission via insect and animals; and (4) offensive odors.

The degree of site management can be expected to vary widely depending on such factors as site ownership, size and planned lifetime, site properties, transportation and application systems and unpredictables such as yearly weather variations. Site management plans should have considerable flexibility.

If the sites are farmer owned and controlled, application must be in harmony with normal farmer operations, whereas long-term lease or community-owned sites can permit more flexible operations. If the site has moderate limitations for any reason, management must take these limitations into account. Inclement weather can upset the best intentions and may dictate marked deviations from any plan.

In some cases, it may be advantageous in terms of site management to double or triple the annual loading rate the year in which sludge application is made and follow this treatment with two or three years of cropping without applying additional sludge. Since subsequent crops would depend heavily on the residual benefits of the sludge, this type of system would work best on medium or heavy textured soils. Such a system would not be recommended on sandy soils, due to the fact that much of the nitrogen would be leached below the root zone during the first year following application.

Contamination of Water Supplies

Runoff must be controlled to minimize the risks of surface water contamination. There are several approaches for runoff control including standard soil conservation practices such as contour farming, strip cropping and terracing. Additionally, catch basins could be constructed to detain runoff water. The latter would be quite expensive, especially if designed for low-probability events (e.g., 100-year storm). A minimum of 100 feet of buffer strip, in a perennial such as alfalfa or grass, should be maintained adjacent to any watercourse. Subsurface applications will minimize runoff problems and should be practiced where feasible.

Since frozen soils do not have the ability to transmit water, extensive runoff can be expected especially during the spring. Therefore, sludge should not be applied to moderately to severely sloping lands when they are frozen. Groundwater contamination can be minimized by use of recommended sludge application rates, and maximizing crop species and yield to ensure adequate crop uptake. Supplemental fertilizer and lime recommendations as indicated by soil test results should be followed. To this end, it is essential that soil sampling for available P and K, and pH (lime requirement) be conducted each fall so that corrective fertilizer and lime applications can be made before the next crop. Proper site selection is essential to prevent pathogen transmission to groundwater.

Sludge should not be surface applied to sloping (>6%) land at any time of the year when a high potential for runoff due to intensive rainstorms exists. Normally, this potential is highest in the spring and late fall, but exists throughout the year in Wisconsin. Therefore, subsurface application or immediate incorporation is advised on all sloping land to overcome the moderate limitation imposed in Table 28.

If a seasonally high groundwater table condition exists, spring application of sludge is not recommended. Therefore, these soils should be managed so that they receive sludge only in the summer and fall.

Liquid sludge is high in soluble salts. Germination and seedling growth of most crops will be inhibited if applied in the seed bed within about two weeks before or after planting. Sufficient time must be given for soluble salts to dissipate before planting.

Metals

Aside from following current recommendations on total metal loading and proper site selection, the major site management variable is soil pH. The soil pH must be maintained at 6.5 or greater at all times, and the soils should be sampled to check on the possible need for liming.

Since some crop species tend to accumulate Cd, care must be taken to avoid these crops, especially if high Cd sludges are being applied. In general, these accumulator crops are the leafy vegetables.

Pathogen Transmission

The best preventive method to minimize pathogen transmission is incorporation of the sludge as soon as possible. Depending on location, it may be advisable to fence the site to limit access by children, pets and the general public.

Odors

If the sludge has offensive odors, the only practical approaches are either location of the site away from populated areas or subsurface application. Sludge application sites should be at least 500 feet from the nearest residence. If the sludge is injected or incorporated into the soil, a reduction in this distance may be possible.

Timing of Application

Timing of application can also be an important management variable. Application too close to planting could result in germination failure due to salt toxicity, while application on growing plants could result in injury to the leaves. Application in the fall could result in less efficient use of nitrogen due to denitrification and/or nitrate leaching. Similarly, application during wet periods, particularly in the spring when the soil is near saturation, could result in a low degree of retention of some pollutants. Therefore, facilities for off-season storage of sludge are required with most agricultural sludge application systems.

IX. SYSTEM MONITORING

Any decision on the intensity of system monitoring must consider: (a) size of the sewage treatment plant and industrial sources of metals; (b) site ownership, site size and planned lifetime; and (c) site properties and management. The system, in this case, refers to the sludge and the site (soil, plants, and surface and groundwater).

Sludge Monitoring

In developing a land application program, representative sludge samples and adequate analyses of the sludge are required. To obtain a representative sample, a number of samples collected periodically over a 24-hour period should be bulked. Samples should be stored in sealed glass or plastic bottles in a refrigerator and analyzed as soon as possible.

It is beyond the scope of this document to give details on how to conduct analyses of sludge. These methods are given elsewhere (Standard Methods, 1971; EPA, 1973). Certain of these analyses, particularly the metals, require complicated instrumentation and trained technicians and, except for larger municipalities, should not be undertaken by the community. Care must be taken with the nitrogen analyses, as ammonia volatilizes readily from the sample and an underestimate of the nitrogen content of the wet sludge can result.

The recommended amount of sludge monitoring is based on sewage treatment plant size. Plants with a treatment capacity of less than 50,000 gallons per day (gpd) require a single sludge analysis yearly which consists of: solids, total nitrogen, ammonium nitrogen, total phosphorus, total potassium, and total metals (including copper, zinc, nickel, chromium, lead and cadmium).

Plants with a treatment capacity of 50,000 to 1,000,000 gpd require all of the analyses listed above plus total arsenic and mercury required once yearly.

Plants with a treatment capacity of > 1,000,000 gpd require all of the analyses listed above, and at least three times during the year.

Site Monitoring

The recommendations for site monitoring are based on the following criteria:

(a) The site meets the qualifications outlined in the section on site selection, and runoff is minimized.

(b) Sludge is being added at fertilizer N rates and nutrient recycling by use of grain, forage or vegetable crops is being practiced.

(c) The sludge is digested or otherwise treated so that pathogen levels are minimal.

(d) Metals and phosphorus are tightly sorbed in the surface soil.

Thus, using recommended practices, ground and surface water contamination can be expected to be essentially at "background" levels, that is, no greater than might occur if commercial fertilizers or animal manures were used rather than sludge.

The recommended monitoring intensity varies with the extent of site use. These are:

(a) Occasional use: Sludge applied at a maximum once every two to three years as part of a normal rotation. This use requires only a soil test every three years to ensure that P, K and pH are adequate for maximum crop yields. Analysis of selected plant material for Cd after three sludge applications may be desirable.

(b) Continuous use: Sludge applied yearly on leased or community-owned land. This use also requires a soil test for K and pH and plant tissue monitoring to evaluate nutrient status and metal uptake. Plant analyses should include Cd, Cu, Mn, Ni, Zn and B. Each site receiving sludge should be tested once every three years.

The plant integrates the various soil and environmental variables involved in the mobility of elements in soil. Therefore, plant tissue analysis will provide the most sensitive and accurate assessment of heavy metal problems. The drawback to plant analysis is that, if a problem is indicated, it may be too late to apply remedial action.

Table 29 lists the range in elemental composition normally encountered in samples of plant tissue in the field and suggested tolerance levels (Melsted, 1973). The tolerance levels given are preliminary values, at this time, and are for succulent vegetative tissue only.

The tolerance levels suggested in Table 29 assume that:

1. The same tolerance levels can be used for the common agronomic crops.
2. The designated plant part and stage of development will be used.
3. The municipal sludges and effluents are being recycled or used as fertilizer. This implies a rate of application commensurate with crop needs.
4. The land is productive agricultural land to be used for crop production for generations to come.
5. Many of the noxious compounds in the wastes become immobile when added to the soil and will remain there indefinitely.
6. The crop will probably absorb a part of any toxic heavy metal or noxious compound added to the soil.
7. The tolerance level includes an acceptable safety factor. Therefore, the suggested levels are only one-half, or less, of the values the literature suggested as being: toxic levels for animals; plant levels at which appreciable transfer of the element from the vegetative portion of the plant to the grain occurs; and the level known to be toxic to the plant itself.

In addition to plant analyses, research on metals extractable from the soil as related to plant toxicity and uptake are being evaluated currently. We hope soon to be able to recommend a "toxic" range of DTPA-extractable Zn, Cu, Ni and Cd in soil. This will be useful to monitor the site and predict possible problems before they occur.

TABLE 29. *Range in normal elemental composition and suggested tolerance level for various elements in succulent vegetative tissue* of agronomic crops, legumes and grasses (Melsted, 1973).*

Element	Normal range (μg/g)	Suggested maximum tolerance level (μg/g)
Cadmium	0.05 - 0.2	3
Cobalt	0.01 - 0.3	5
Copper	3 - 40	150
Manganese	15 - 150	300
Mercury	0.001 - 0.01	0.04
Nickel	0.01 - 1.0	3
Lead	0.1 - 5.0	10
Zinc	15 - 150	350
Arsenic	0.01 - 0.1	2
Boron	7 - 75	150
Molybdenum	0.2 - 1.0	3
Selenium	0.05 - 2.0	3
Vanadium	0.1 - 1.0	2

*Values are for corn leaves at or opposite and below ear level at tassel stage; soybeans–the youngest mature leaves and petioles on the plant after first pod formation; legumes–upper stem cuttings in early flower stage; cereals–the whole plants at boot stage; grasses–while plants at early hay stage. All plant samples should be washed with deionized-distilled water before drying to remove any surface contamination. In some cases it may be necessary to wash with a detergent solution or a weak acid solution before the final washing with deionized-distilled water. Samples should be dried (65°C) as quickly as possible, ground, and stored for analysis. If the undried samples cannot be processed immediately, they should be placed in polyethylene bags and stored under refrigeration. Preparation for analysis involves: (1) Wet digestion. For all elements except N and B. Digest in boiling nitric-perchloric acids. Treatment with HF may be necessary for recovery of some of the heavy metals from the silica which precipitates in the digest. (2) Dry ashing. At low temperature (450 to 500°C). Dissolve ash in HCl. This is the only method to be used for B analysis. Not suitable for Hg, S, Se, As, Ag, Fe, Sb, and N. (3) Kjeldahl (H_2SO_4) digestion. For total N, P, and K.

X. SLUDGE APPLICATION TO NONAGRICULTURAL LANDS

Forests offer a viable alternative for sludge disposal, particularly during adverse weather and for small communities. The sites chosen may often be in National, State or locally-owned forests. To date, little long-term information is available on the impact of sludge disposal on the forest environment, but results of the few short-term studies indicate that if the site is properly managed, environmental impact is minimal and some stimulation in tree growth can occur. Further studies may well show highly beneficial effects of sludge for stimulation of regrowth on whole-tree harvested sites, Christmas tree plantations, and fast-growth chipwood systems such as hybrid poplar. In these systems a high degree of nutrient recycling can be expected and the pathogen problems will be minimal as compared to agricultural systems.

Since forested sites can often be located in isolated areas, problems with odors and public acceptance will be minimized, and the main potential problem will be nitrate pollution of the groundwater. Thus nitrogen loading should be limited to an annual total of 100 lb/A of available nitrogen, and monitoring wells established to ensure that excessive nitrate-nitrogen contamination of the groundwater does not occur. Further, background levels of metals in adjacent foliage should be established, and monitoring of foliage for excessive metals conducted every third year. Due to the difficulty in raising soil pH in forested sites, metals may prove to be a particularly difficult problem, necessitating low total loadings.

Park lands also offer an alternative application site, especially during adverse weather. Since these lands are also publicly owned, site acquisition problems are minimal. However, easy public access and low rates of nutrient recycling present problems. Subsurface application is a necessity, and low rates (150 to 200 lb/A) of available nitrogen once every three to four years would be a maximum loading rate.

Several studies have shown that sewage sludge is excellent for rejuvenation of despoiled land, such as strip-mine spoils, mine tailings, scalped land and other areas where the land has been grossly altered. The quantity of sludge needed to restore such areas depends on the nature of the land being treated. For example, acid coal mine spoil reclamation in southern Illinois required about 200 to 250 dry tons per acre, while with calcareous and strongly alkaline spoils, about 100 to 200 dry tons per acre of sludge markedly improved plant growth (Lue-Hing et al., 1974). Of course, at these rates, substantial amounts of NO_3-N will be leached. However, restoring these lands to productive use more than offsets the temporary high nitrate hazards of a localized area.

SUMMARY

Wastewater sludges contain the concentrated wastes of the community. This includes all of the plant nutrients, but in particular nitrogen and phosphorus. Certain sludges also contain potentially toxic and hazardous components, principally the heavy metals, pathogenic bacteria and virus.

In many instances, disposal of sludge on agricultural land is the most cost-effective (for the community) and environmentally sound approach. This involves the concept of "recycling" the plant nutrients. However, a number of precautions must be taken to minimize the possibilities of disease transmission, water quality degradation by nitrogen and phosphorus and soil contamination by the heavy metals to levels detrimental to crop yields. These must be taken into account in facilities' planning of new sewage treatment systems receiving state and federal grants.

Sludge is a low analysis fertilizer of extremely variable quality. The economics of sludge disposal from the farmer standpoint is a dynamic situation depending on fertilizer cost and availability.

Another major potential problem which has occurred with many of the wastewater and sludge land application projects to date is acceptance of the project by the local population. A thorough educational program, complete with alternatives to the proposed plan, is required. A major public acceptance problem is the odor, real or imagined, associated with sludge. One way to minimize this problem is to incorporate the material in the soil as soon as possible.

Commercially available equipment may be readily modified for surface or subsurface application of sludge. Dewatered sludge (> 15% solids) can be handled as a solid by using equipment designed for farm animal manures, while liquid sludge (< 15% solids) may be applied to the surface by tank truck or spray irrigation, or injected by equipment designed for use with liquid farm wastes.

Several studies have shown that sewage sludge applied at the proper rates will supply the nitrogen and phosphorus needs of agronomic crops and that sludge treated fields will produce yields comparable to that attained with use of commercial fertilizers. Sewage sludge nitrogen is in the form of ammonium and organic nitrogen. The ammonium nitrogen is readily available to crops, but a considerable amount of this nitrogen can be lost to the atmosphere by volatilization if the sludge is applied to the soil surface and allowed to dry. A ton of sludge solids might contain up to 30 or 40 pounds of ammonium-nitrogen and 50 pounds of organic nitrogen. However, only 15 to 20% of the organic nitrogen is available through the decomposition process the year of application. Thus, the available nitrogen in a ton of sludge solids might be around 40 to 50 pounds if injected and 25 to 30 pounds if surface applied.

This nitrogen must be balanced against crop needs. Depending on the length of the growing season, the type of soil, the supply of available nitrogen from the soil and the level of management, a corn crop may need from 60 to 200 pounds of fertilizer nitrogen/acre. At fertilizer nitrogen rates, and assuming that proper site preparation has been used, environmental contamination by nitrate should be minimal and ground water monitoring is not required.

The phosphorus in sludge is also beneficial. A ton of sludge solids would contain from 40 to 100 pounds of phosphorus. Thus, if sludge is added at nitrogen fertilizer rates, much more phosphorus is added than needed by the crop. Experience to date has indicated that this excess phosphorus is not a problem when sludge is used at fertilizer nitrogen rates. Sludge is deficient in potassium relative to crop needs (corn, for example, has an N:P:K ratio of 5:1:5), and a management program must involve soil tests for available potassium and supplemental addition of potassium fertilizer as required.

Sewage sludge, as it comes from the digester, contains a variety of pathogens, including bacteria, larvae, worms and virus. Available evidence indicates that, with time, these pathogens die off so that in about 2 months or so of storage, about a 90 to 99% decrease in their numbers occurs. Several sterilization methods are also available to reduce the pathogen content of sludges. When the sludge is added to soil, these pathogens are not able to compete with the native soil microorganisms, and they practically disappear in a few weeks. There have been no documented reports of disease problems with sludge, but to be on the safe side, precautions must be taken. This includes limiting public access to the application site, minimizing runoff, and restrictions on grazing or growing of vegetables on the site the year of application.

Another potential problem is the heavy metals in sludges, particularly those from communities with certain types of industries. These metals may be toxic to plant life if added in sufficient amounts, thus leaving the soil unusable for agricultural pursuits. Certain of these metals may also accumulate in the plant tissue and be a hazard to animals and humans consuming the plant tissue. These metals are tightly held by the organic and inorganic constituents in soils. As soil pH increases, availability of these metals decreases. The more organic matter and clay a soil contains, the more metals can be added before problems occur. Thus the metal retention capacity of a soil and the metal load of the sludge must also be taken into account when designing a sludge application program.

RECOMMENDATIONS

The following recommendations are made regarding the application of wastewater sludge to agricultural land in Wisconsin:

1. Raw sludge should not be applied to agricultural land.
2. Sludges should be applied to soils consistent with the nitrogen needs of the crops being grown.
3. At least 2 feet and preferably greater than 4 feet of soil should exist between the sludge application zone and bedrock, any impermeable layer, or the water table.
4. To ensure adequate protection of water supplies, the sludge application site should be a minimum of 1,000 feet from the nearest public water supply well and 500 feet from the nearest private water supply well.
5. Sludge should not be applied to soil in the year the area is used for any root crops or other vegetables which are consumed uncooked.
6. If sludge is surface applied to sloping land, runoff should be minimized by use of contour strips, terraces and border areas. Also, runoff can be reduced by injection or immediate incorporation of the sludge.
7. Pasture land (or crops which are harvested green) should not be used for milk cow feeding for two months following sludge application. Other animals should not graze pasture land or be fed green chop material for at least two weeks after sludge application.
8. Metal loadings must be kept within acceptable limits to minimize the potential of crop damage or food chain accumulation. The soil pH must be maintained at 6.5 or greater.
9. Application systems must be such that they minimize the runoff potential and odor problems while remaining cost-effective.
10. Sludge application sites should be at least 500 feet from the nearest residence. If the sludge is injected or incorporated into the soil a reduction in this distance may be possible.
11. Site management must be such that nutrient deficiency and soil acidity problems do not occur, public access is limited, and crop yields are maximized.
12. Site monitoring should be the responsibility of the municipality. If sludge additions consistent with nitrogen requirements are used, monitoring needs include only sludge and plant analyses as well as routine soil testing. If higher rates are to be applied on dedicated land, comprehensive ground water monitoring must be included.

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APPENDIX

A. YIELD POTENTIAL AND LIMITATIONS OF MAJOR WISCONSIN SOIL SERIES FOR APPLICATION OF WASTEWATER SLUDGE*

Name of Soil Series	Yield Pot.[a]	Limitation[b] Rating	Limitation[b] Factor
Adolph	3	Severe	2, 3
Adrian	1	Severe	2, 9
Ahmeek	4	Moderate	7
Alban	3	Slight	
Alcona	3	Moderate	6
Allendale	4	Moderate	1
Almena	3	Moderate	1
Alstad	3	Moderate	1
Altdorf	3	Severe	2, 3
Amery	2	Slight	
Angelica	3	Severe	2, 3
Antigo	2	Slight	
Arcola	3	Moderate	7
Arenzville	1	Severe	3
Arland	3	Slight	
Ashdale	1	Slight	
Ashkum	2	Severe	2, 3
Auburndale	3	Severe	2, 3
Au Gres	4	Severe	1, 9
Aztalan	1	Moderate	1, 7
Baraboo	2	Moderate	4
Barrington	1	Slight	
Barronett	2	Severe	2, 3
Basco	2	Moderate	4
Batavia	1	Slight	
Beecher	2	Moderate	7
Bellevue	1	Severe	3
Bergland	4	Severe	3, 8
Bertrand	1	Slight	
Bevent	3	Moderate	6
Bibon	4	Severe	9
Billett	3	Moderate	6
Blount	2	Moderate	1, 7
Boaz	2	Severe	3
Bohemian	3	Slight	
Bonduel	2	Moderate	1
Boone	4	Severe	9
Boots	1	Severe	2, 3
Borth	2	Moderate	7
Boyer	3	Moderate	6
Braham	3	Slight	
Brems	3	Severe	9
Brickton	2	Severe	2, 7
Briggsville	2	Moderate	7
Brill	2	Moderate	1
Brimley	3	Moderate	1
Brookston	1	Severe	2, 3
Bruce	3	Severe	2, 3
Brule	3	Severe	3
Burkhardt	3	Moderate	6
Cable	4	Severe	2, 3
Cadiz	1	Slight	
Cadott	2	Moderate	1, 6
Calamine	1	Severe	2, 8
Campia	2	Slight	
Carbondale	1	Severe	2, 3
Carlisle	1	Severe	2, 3
Caryville	2	Severe	3, 9
Casco	3	Moderate	6
Cathro	1	Severe	2
Channahon	3	Severe	5, 9
Chaseburg	1	Severe	3
Chelsea	4	Severe	9
Chetek	3	Moderate	6
Clifford	3	Moderate	1, 7
Cloquet	3	Moderate	6
Clyde	2	Severe	2, 3
Coloma	4	Severe	9
Colwood	1	Severe	2, 3
Comstock	2	Moderate	1
Crivitz	4	Moderate	6
Cromwell	3	Moderate	6
Croswell	4	Severe	1, 9
Crown	3	Moderate	1, 6
Crystal Lake	2	Slight	
Curran	1	Moderate	1, 7
Cushing	3	Slight	
Dakota	2	Moderate	6
Dalbo	3	Moderate	1, 7
Dancy	3	Severe	2, 3
Darroch	1	Moderate	1
Dawson	1	Severe	2, 3
Deford	4	Severe	2, 3
Dells	2	Moderate	1, 6
Del Rey	2	Moderate	1, 7
Delton	2	Slight	
Denrock	1	Moderate	1, 7
De Pere	2	Severe	3, 8
Derinda	2	Moderate	7
Dickinson	2	Moderate	6
Dickman	3	Moderate	6
Dodge	1	Slight	
Dodgeville	2	Moderate	4
Dolph	3	Severe	1, 8
Downs	1	Slight	
Dresden	2	Slight	
Dubuque	2	Moderate	4
Duelm	3	Moderate	6
Duluth	3	Slight	
Dunbarton	3	Severe	5
Dunnville	1	Slight	
Durand	1	Slight	
Dusler	3	Moderate	7
Eagle	2	Slight	
East Lake	4	Severe	9
Eau Pleine	2	Slight	
Edmund	2	Severe	5
Edwards	1	Severe	2, 3
Elburn	1	Severe	2, 3
Elderon	4	Slight	
Elroy	1	Slight	
Eleva	3	Moderate	4
Elkmound	3	Severe	5
Elliott	2	Moderate	7
Elm Lake	3	Severe	2, 3
Elvers	1	Severe	2, 3
Emmert	3	Severe	9
Emmet	3	Slight	
Ettrick	1	Severe	2, 3
Fabius	3	Moderate	1, 6
Fairchild	3	Moderate	1, 6
Fall Creek	1	Moderate	1, 7
Fayette	1	Slight	
Fence	3	Slight	
Fenwood	2	Slight	
Fifield	3	Moderate	1
Flagg	1	Slight	
Floyd	2	Moderate	1, 3
Fox	2	Slight	
Freeon	3	Slight	
Freer	3	Moderate	1, 7
Friendship	3	Severe	1, 9
Friesland	2	Slight	
Gaastra	3	Moderate	1
Gale	2	Moderate	4
Garwin	1	Severe	2, 3
Gilford	3	Severe	2, 3
Gogebic	4	Slight	
Goodman	3	Slight	
Gotham	3	Moderate	6
Granby	4	Severe	3, 9
Gratiot	1	Moderate	1, 7
Grays	1	Slight	
Greenwood	1	Severe	2, 3
Grellton	2	Slight	
Griswold	2	Slight	
Guenther	3	Moderate	6
Halder	3	Moderate	1, 3
Hebron	1	Moderate	7
Hennepin	2	Slight	
Hertel	4	Moderate	6
Hesch	3	Moderate	4
Hiawatha	4	Severe	9
Hibbing	4	Moderate	7
Hiles	2	Moderate	4
Hitt	2	Slight	
Hixton	3	Moderate	4
Hochheim	2	Slight	
Hortonville	2	Slight	
Houghton	1	Severe	2, 3
Hubbard	3	Severe	9
Humbird	4	Moderate	4, 6
Huntsville	1	Severe	3
Iosco	3	Moderate	1
Iron River	4	Slight	
Isanti	3	Severe	2, 9
Jackson	1	Slight	
Jericho	1	Moderate	7
Jewett	2	Slight	
Joliet	2	Severe	2, 5
Joy	2	Moderate	1
Juda	1	Slight	
Jump River	3	Severe	3
Juneau	1	Severe	3
Kane	2	Moderate	1
Karlin	3	Moderate	6

A. (Cont.)

Name of Soil Series	Yield Pot.[a]	Limitation[b] Rating	Factor
Kato	2	Severe	2, 3
Kaukauna	2	Moderate	7
Kegonsa	2	Slight	
Keltner	1	Slight	
Kendall	1	Slight	
Kennan	3	Slight	
Kenyon	2	Slight	
Keowns	2	Severe	2, 3
Kert	2	Moderate	1, 4
Kewaunee	2	Moderate	7
Kibbie	2	Moderate	1
Kickapoo	1	Severe	3
Kidder	2	Slight	
Kinross	4	Severe	1, 9
Kiva	4	Moderate	6
Knowles	2	Moderate	4
Kolberg	3	Moderate	4
Kranski	3	Severe	9
La Farge	2	Slight	
Lafont	3	Slight	
Lamartine	1	Moderate	1
Lamont	3	Moderate	6
Langlois	1	Slight	
Lapeer	2	Slight	
Lawler	2	Moderate	1
Lawson	1	Severe	1, 3
Leola	4	Moderate	1, 6
LeRoy	3	Slight	
Lindstrom	1	Slight	
Lino	3	Moderate	1, 6
Linwood	1	Severe	2, 3
Lobo	1	Severe	2, 3
Lomira	2	Slight	
Longrie	3	Moderate	4
Lorenzo	3	Moderate	6
Lows	3	Severe	2, 3
Loyal	2	Slight	
Ludington	4	Moderate	4, 6
Lunds	3	Moderate	1, 6
Lupton	1	Severe	2, 3
Mackinac	3	Moderate	1, 6
Magnor	3	Moderate	1, 6
Manawa	2	Moderate	1, 7
Manistee	4	Moderate	7
Manitou	4	Severe	2, 3
Mann	3	Severe	2, 3
Marathon	2	Slight	
Marcellon	2	Moderate	1
Markesan	2	Slight	
Markey	1	Severe	2, 3
Markham	2	Slight	
Marshan	2	Severe	2, 3
Marshfield	2	Severe	2, 3
Martinsville	2	Slight	
Martinton	2	Moderate	1, 7
Matherton	2	Moderate	1
Maumee	4	Severe	2, 3
Mayville	1	Slight	
McHenry	2	Slight	
Meadland	2	Moderate	1, 7
Mecan	3	Moderate	6
Medary	2	Moderate	7
Meehan	3	Severe	1, 9
Menchgo	4	Severe	9
Mendota	2	Slight	
Menominee	3	Moderate	6
Mequon	2	Moderate	1, 7
Meridian	3	Slight	
Merrillan	3	Moderate	1, 4
Metamora	2	Moderate	1, 6
Metea	3	Moderate	6
Miami	2	Slight	
Mifflin	3	Slight	
Military	3	Moderate	4
Milladore	2	Moderate	1
Minocqua	3	Severe	2, 3
Monico	4	Severe	2
Montello	2	Moderate	7
Montgomery	2	Severe	2, 3
Montmorenci	1	Slight	
Morley	2	Moderate	7
Morocco	3	Severe	1, 9
Mosel	1	Moderate	1, 7
Mosinee	3	Slight	
Moundville	3	Moderate	1, 6
Mt. Carroll	1	Slight	
Mundelein	1	Moderate	1
Munising	4	Moderate	7
Muscatine	1	Moderate	1
Muskego	1	Severe	2, 3
Mussey	3	Severe	2, 3
Mylrea	2	Moderate	1
Myrtle	1	Slight	
Namur	3	Severe	5
Navan	1	Severe	2, 3
Neda	2	Slight	
Nemadji	4	Severe	1, 9
Nenno	2	Moderate	1
Newaygo	3	Slight	
New Glarus	2	Moderate	4
Newson	3	Severe	2, 9
Newton	4	Severe	2, 9
Nichols	2	Slight	
Nickin	3	Moderate	4
Nippersink	2	Slight	
Norden	2	Moderate	4
Norgo	3	Severe	5
Norrie	2	Slight	
Northfield	3	Severe	5
Nymore	3	Severe	9
Oakville	3	Severe	9
Ockley	1	Slight	
Oconto	3	Moderate	6
Odell	1	Moderate	1
Oesterle	3	Moderate	1
Ogden	1	Severe	2, 3
Okee	3	Slight	
Omega	4	Severe	9
Omena	2	Slight	
Omro	2	Moderate	7
Onamia	3	Moderate	6
Onaway	3	Slight	
Ontonagon	3	Moderate	7
Orienta	4	Moderate	6
Orion	1	Severe	3
Oshkosh	2	Severe	8
Oshtemo	4	Moderate	6
Ossian	1	Severe	2, 3
Otter	1	Severe	2, 3
Otterholt	2	Slight	
Ottokee	4	Moderate	6
Ozaukee	2	Moderate	7
Padus	3	Slight	
Palms	1	Severe	2, 3
Palsgrove	2	Slight	
Pardeeville	2	Slight	
Parr	1	Slight	
Pearl	4	Severe	9
Pecatonica	1	Slight	
Peebles	3	Moderate	7
Pella	1	Severe	2, 3
Pence	3	Moderate	6
Pickford	3	Severe	2, 8
Pillot	2	Slight	
Pinconning	4	Severe	2, 3
Plainbo	4	Severe	9
Plainfield	4	Severe	9
Plano	1	Slight	
Pleine	4	Severe	2, 3
Plover	3	Moderate	1
Point	3	Moderate	1
Port Byron	1	Slight	
Poskin	3	Moderate	1
Poy	2	Severe	2, 9
Poygan	2	Severe	2, 9
Puchyan	2	Moderate	6
Racine	2	Slight	
Radford	1	Severe	1, 3
Renova	2	Slight	
Rib	3	Severe	2, 3
Richford	4	Moderate	6
Richter	3	Moderate	1
Richwood	1	Slight	
Rietbrock	2	Moderate	1, 4
Rifle	1	Severe	2
Rimer	3	Moderate	1
Ringwood	2	Slight	
Ripon	2	Moderate	4
Ritchey	3	Severe	5
Rockers	4	Moderate	1
Rockton	2	Moderate	4
Rodman	4	Severe	9
Roscommon	4	Severe	2, 9
Rosholt	3	Moderate	6
Rotamer	3	Slight	
Rousseau	4	Severe	9
Rowley	1	Moderate	1
Rozellville	2	Slight	
Rubicon	4	Severe	9

* The assistance of A.J. Klingelhoets, USDA-SCS is gratefully acknowledged.

a Yield potential for corn: 1. Very high, 2. High, 3. Moderate, 4. Low.

b The soil series listed here have been rated in accordance with the following limitation factors:
1. Water table at 2-4 ft
2. High water table (<2 ft)
3. Occasional flooding, ponding
4. Bedrock at 2-4 feet
5. Shallow to bedrock (<2 ft)
6. Permeability: moderately rapid (2 to 6 in/hr)
7. Permeability: moderately slow (0.2 to 0.6 in/hr)
8. Permeability: slow (less than 0.2 in/hr)
9. Permeability: rapid (more than 6 in/hr)

Final determination of the rating by the site investigator must be based on separate consideration of slope limitations: Slight limitations, 0 to 6%; Moderate limitations, 6 to 12%; Severe limitations, greater than 12%. For a particular site, then, the final limitation is determined by the most restrictive rating.

A. (Cont.)

Name of Soil Series	Yield Pot.[a]	Limitation[b] Rating	Factor
Rudolph	3	Moderate	7
Rudyard	3	Moderate	1, 3
Ruse	4	Severe	2, 4
Sable	1	Severe	2, 3
St. Charles	1	Slight	
Salter	2	Slight	
Santiago	2	Slight	
Sargeant	2	Severe	2
Sartell	3	Severe	9
Sattre	3	Slight	
Sawmill	1	Severe	2, 3
Saylesville	2	Moderate	7
Schapville	2	Moderate	7
Scott Lake	3	Slight	
Seaton	1	Slight	
Sebewa	2	Severe	2, 3
Seelyeville	1	Severe	2, 3
Selkirk	3	Moderate	7
Seward	3	Moderate	6
Shawano	4	Severe	9
Sheboygan	1	Severe	2, 3
Sherry	2	Severe	2, 3
Shiffer	3	Moderate	1
Shiocton	2	Moderate	1
Shullsburg	2	Moderate	4
Sisson	2	Slight	
Skillet	2	Moderate	1, 4
Skyberg	2	Moderate	1, 7
Sogn	4	Severe	5
Solona	3	Moderate	1
Spalding	1	Severe	2, 3
Sparta	4	Severe	9
Spencer	2	Slight	
Spinks	4	Moderate	6
Spirit	3	Moderate	1
Stambaugh	3	Slight	
Strawn	2	Slight	
Stronghurst	2	Moderate	1
Summerville	3	Severe	5
Superior	4	Moderate	7
Sylvester	2	Moderate	4
Symco	2	Moderate	1
Symerton	1	Moderate	7
Tama	1	Slight	
Tawas	1	Severe	2, 3
Tedrow	3	Severe	1, 9
Tell	2	Slight	
Terril	1	Severe	3
Thackery	1	Moderate	1
Theresa	2	Slight	
Tilleda	3	Slight	
Toddville	1	Slight	
Trempe	4	Severe	9
Trempealeau	2	Moderate	6
Trenary	3	Moderate	7
Troxel	1	Severe	3
Tula	4	Moderate	1
Tustin	3	Slight	
Underhill	3	Slight	
Urne	3	Moderate	4
Valton	2	Moderate	7
Varna	2	Moderate	7
Veedum	3	Severe	2, 3
Vesper	2	Severe	2, 3
Vilas	4	Severe	9
Virgil	1	Moderate	1
Vlasaty	2	Slight	
Wacousta	2	Severe	2, 3
Wainola	4	Severe	1, 9
Wakefield	3	Slight	
Wallkill	1	Severe	2, 3
Warman	3	Severe	2, 3
Warsaw	2	Slight	
Wasepi	3	Moderate	6
Washburn	3	Slight	
Washtenaw	2	Severe	2, 3
Waterloo	2	Slight	
Watseka	4	Severe	1, 9
Waubesa	1	Severe	2, 3
Wauconda	1	Moderate	1
Waukechon	3	Severe	2
Wauseon	2	Severe	2
Wautoma	2	Severe	2
Waymor	2	Slight	
Wea	1	Slight	
Westland	1	Severe	2
Westville	2	Slight	
Whalan	2	Moderate	4
Whitehall	2	Slight	
Will	2	Severe	2, 3
Willette	1	Severe	2, 3
Wilton	2	Moderate	7
Winnebago	1	Slight	
Winneconne	2	Severe	8
Winneshiek	2	Moderate	4
Withee	2	Moderate	1
Worchester	3	Moderate	1
Worthen	1	Severe	3
Wyeville	3	Moderate	6
Wykoff	3	Slight	
Wyocena	3	Moderate	6
Yahara	2	Moderate	1
Zittau	2	Moderate	7
Zurich	1	Slight	
Zwingle	2	Severe	2, 3

* The assistance of A.J. Klingelhoets, USDA-SCS is gratefully acknowledged.

a Yield potential for corn: 1. Very high, 2. High, 3. Moderate, 4. Low.

b The soil series listed here have been rated in accordance with the following limitation factors:
1. Water table at 2-4 ft
2. High water table (< 2 ft)
3. Occasional flooding, ponding
4. Bedrock at 2-4 feet
5. Shallow to bedrock (< 2 ft)
6. Permeability: moderately rapid (2 to 6 in/hr)
7. Permeability: moderately slow (0.2 to 0.6 in/hr)
8. Permeability: slow (less than 0.2 in/hr)
9. Permeability: rapid (more than 6 in/hr)

Final determination of the rating by the site investigator must be based on separate consideration of slope limitations: Slight limitations, 0 to 6%; Moderate limitations, 6 to 12%; Severe limitations, greater than 12%. For a particular site, then, the final limitation is determined by the most restrictive rating.

B. FIELD INFORMATION SHEET

Part A
Characteristics of Digested Sludge

Name of Treatment Plant ____________________
Permit No. WI– ____________________
Analysis of Digested Sludge*

Total N	______ %	As	______ ppm	Ni	______ ppm
NH_4-N	______ %	Cd	______ ppm	Zn	______ ppm
Total P	______ %	Cu	______ ppm		
Total K	______ %	Cr	______ ppm		
pH	______	Pb	______ ppm		
Solids	______ %	Hg	______ ppm		

Laboratory Doing Analysis ____________________
Date of Analysis ____________________
*All analysis on a dry weight basis except percent solids.

Part B
Site Evaluation and Application Rate Calculations

Name of Treatment Plant ____________________
Permit No. WI– ____________________
Sludge Application Site
(Attach soil survey map of field location and soil test results)
Location Township ______ Range ______ Section ______ County ______
Owner's Name ____________________ Address ____________________
____
Operator's Name ____________________ Address ____________________
____

Predominant Soil Series ____________________
Predominant Soil Texture ____________________
Slope: ☐ Nearly Level (0-6%) ☐ Sloping (6-12%) ☐ Steep (>12%)
Distance To The Nearest Residence (In Feet) ____________________
Distance To The Nearest Public Water Supply
(In Feet) ____________________
Distance To The Nearest Private Water Supply
(In Feet) ____________________
Sludge To Be Used For ☐ Cropland ☐ Reclaiming Marginal Land
☐ Other ____________________
Application Method ____________________
Describe Any Special Problems In Cropping In This Field ____________________
____

Soil Test Results
Testing Lab ____________ Date Tested ____________ Recommendations
Soil pH ____________ For ____________ (Crop)
Organic Matter ____________ Tons/A Lime ____________ Tons/A
Available P ____________ Lbs/A Fertilizer
Exchangeable K ____________ Lbs/A N ____________ Lb/A = (A)
P_2O_5 ____________ Lb/A = (P)
K_2O ____________ Lb/A = (K)

I. CALCULATION OF SLUDGE APPLICATION RATE (DRY SOLIDS BASIS) BASED ON NITROGEN

Sludge Analysis:
NH_4-N ______ % Organic N (Equals Total N Minus NH_4-N) ______ %
P ______ % K ______ %

1. Available N in Sludge
______ (% NH_4-N) x 20 x 0.5 (If Surface Application) = (B) ______ Lb/Ton
______ (% Org. N) x 3 = (C) ______ Lb/Ton
2. Residual N From Table 11
(D) ____ Lb/A = ______ (2nd Year) + ______ (3rd Year) + ______ (4th Year)
3. Sludge Application Rate, Tons/A/Year = $\frac{(A) - (D)}{(B) + (C)}$ = ______ Tons/A/Yr = (E)

B. (Cont.)

II. CALCULATION OF SLUDGE APPLICATION RATE BASED ON HEAVY METALS

Sludge Analysis:

Zn ________ ppm   Cu ________ ppm
Ni ________ ppm   Cd ________ ppm

1. Total Metal Equivalent Loading Based On Soil CEC
   = 65 x CEC = ____________ Lb. Metal Equivalents/A Or Estimate From Table 19 = (F)
2. Metal Equivalents/Ton of Sludge =

$$\frac{\text{ppm Zn} + 2(\quad \text{ppm Cu}) + 4(\quad \text{ppm Ni})}{500}$$

   = _____ Lb. Metal Equivalents/Ton = (G)
3. Metal Loading Per Year Based On Nitrogen Fertilizer Rates
   = (E) _____ Ton/A/Yr x (G) _____ Lb/Ton = _____ Lb/A/Yr = (H)
4. Site Lifetime Based On Use Of Sludge At Nitrogen Fertilizer Rates

$$= \frac{(F)\ \text{Total Lb. Metal Equivalents/A}}{(H)\ \_\_\_\_\_\ \text{Metal Equivalents, Lb/A, Yr.}} = \_\_\_\_\_\ \text{Yr.}$$

III. YEARLY AND MAXIMUM LOADING LIMITS BASED ON Cd

1. Yearly Limit of 2 Lb. Cd/A = $\frac{2 \times 500}{\_\_\_\_\ \text{ppm Cd}}$ = ________ Tons/A/Yr = (I)
2. Maximum Loading, 20 Lb. Cd/A = $\frac{20 \times 500}{\_\_\_\_\ \text{ppm Cd}}$ = ________ Tons/A = (J)

IV. POTASSIUM FERTILIZER NEEDS

1. Maximum Yearly Application Rate = (E) or (I), Whichever Is Smaller.
2. K_20 Added in Sludge = Sludge Rate, (E) or (I) Ton/A/Yr x $\frac{\%K}{100}$ x 2,000 Lb/Ton x 1.2

   = ________ Ton/A/Yr x 24 Lb/Ton = ________ Lb. K_20/A/Yr = (J)
   = (K) ________ − (J) ________ = ________ Lb/A

C. SOME USEFUL CONVERSION FACTORS

1. 1 acre = 4,840 yards^2 = 43,560 feet^2 = 4,047 meters^2 = 0.4047 hectare
2. 1 acre-inch of liquid = 27,154 gallons = 3,630 ft.^{3} = 102,787 liters
3. 1 acre-inch of 5% (by weight) sludge = 6 tons of solids/acre = 13.45 metric tons/hectare
4. acre-inches X 0.226 X mg/liter = lb/acre
5. hectare-cm X 0.1 X mg/liter = kg/hectare
6. hectare-cm
7. hectare-cm of liquid = 100,000 liters = 100m^3
8. 1 metric ton = 1,000 kg = 2,205 lb
9. English-Metric Conversions
   a. acre-inch X 102.8 = meter^3
   b. quart X 0.946 = liter
   c. English ton X 0.907 = metric ton
   d. English ton/acre X 2.242 = metric ton/hectare
   e. lb/acre X 1.121 = kg/hectare
   f. 1 ft^3 = 7.48 gallons = 28.3 liters = 62.4 lbs water
   g. 1 lb = 0.454 kg

APPENDIX D

NITROGEN APPLICATION RATE CALCULATIONS

Appendix D

Amount of Area Required for Land Application of the Final Compost Product

Compost Specifications				
Component	% Nitrogen as is	% Nitrogen dry	Dry Material (lbs/day)	Nitrogen (lbs/day)
Nitrocellulose	12.63%	14.14%	1250	176.8
Horse Manure	1.36%	2.60%	563	14.7
Straw	0.67%	0.73%	687	5.0

Amount of final compost to be disposed of (dry):

per day	2500	lbs/day
per cycle	90000	lbs/cycle
per year	900000	lbs/year
	450	tons/year

Calculation Assumptions

Nitrogen from Nitrocellulose is NO_3 =	176.8	(lbs/day)
Nitrogen from all other sources is NH_4 =	19.6	(lbs/day)

The Amount of Nitrogen available for vegetation uptake is given by:

$N_a = K_N [NO_3 + k_v (NH_4) + f_n(N_0)]$

where:

K_N =	2000	lbs/ton dry solids
NO_3 =	7.07%	(percent of NO_3 in the compost)
k_v	0.5	(volatilization factor of 0.5 or 1.0)
NH_4 =	0.79%	(percent of NH_4 in the compost)
f_n =	0.1	
N_0 =	0	(percent of organic Nitrogen in the compost)

N_a = 149.3 lbs/ton dry solids

The amount of organic compost which is available in subsuquent years is given by:

$(N_a)_X = (N_a)_1 + K_N [f_2(N_0)_2 + f_3(N_0)_3 + \ldots + f_X(N_0)_X]$

Application Yr	f_n	$(N_0)_n$	$f_n(N_0)_n$	$(N_a)_n$
1st	0.1	0.0000	0.0000	
2nd	0.05	0.0000	0.0000	149.3
3rd	0.03	0.0000	0.0000	149.3
4th	0.03	0.0000	0.0000	149.3
5th	0.03	0.0000	0.0000	149.3

$(N_a)_X = N_a$ since it is assumed the compost contains no organic nitrogen

$(N_a)_X = N_a$ 149.3 lbs/ton dry solids

Appendix D

Amount of Area Required for Land Application of the Final Compost Product

The amount of compost which can be applied annually is given by:

$R_N = U_N / (N_a + N_{pn})$

where:

$U_N =$ $\boxed{210}$ lbs/acre (Annual Nitrogen uptake by vegetation)

R_N = **1.4 tons of compost/acre**

The area required for the application of the compost with the specified quantities is given by:

$A = Q_s / R_N$

Q_{day} =	1.25 tons of dry solids
Q_{cycle} =	45 tons of dry solids
Q_{year} =	450 tons of dry solids

Area/day =	0.89 acre
Area/cycle =	32 acres
Area/year =	320 acres